Return this book on or before the
Latest Date stamped below.

University of Illinois Library

OCT 31 1953
JAN 30 1956
APR 24 1958
NOV 25 1958
JAN 10 1968
MAY -6 1969
NOV 22 1973
NOV 30 1973
APR 27 1976
APR 27 1976
AUG 18 1976
AUG 17 1976

L161—H41

A SYMPOSIUM

Psychophysiological Factors in SPATIAL ORIENTATION

PENSACOLA, FLORIDA - OCTOBER 1950

OFFICE OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
WASHINGTON D.C.

NAVEXOS P-966

Digitized by the Internet Archive
in 2018 with funding from
University of Illinois Urbana-Champaign Alternates

https://archive.org/details/symposiumonpsych00unit

A SYMPOSIUM

Psychophysiological Factors in SPATIAL ORIENTATION

Papers presented under the auspices of the
PSYCHOPHYSIOLOGY BRANCH
OFFICE OF NAVAL RESEARCH

at a meeting of the
Naval Research Advisory Panel in Psychophysiology

in cooperation with the

U. S. NAVAL SCHOOL OF AVIATION MEDICINE
U. S. Naval Air Station
Pensacola, Florida

30-31 October 1950

OFFICE OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
WASHINGTON D.C.

NAVEXOS P-966

616.98
Sy 6p

CONTENTS

Attendance List iii
Foreword v

INTRODUCTION

Spatial Disorientation in Flight 3
Capt. Ashton Graybiel, MC, USN
School of Aviation Medicine, Pensacola

EXPERIMENTAL

Neurophysiological Factors

Anatomy and Physiology of the Vestibular System 11
Harlow W. Ades
Emory University

Cortical Projection of Postural Impulses 15
Walter A. Mickle and Harlow W. Ades
Emory University

Orientation to Visual and Postural Vertical

Individual Differences in Mode of Space Orientation 18
Herman A. Witkin
Brooklyn College

Factors Influencing the Perception of the Vertical 30
Cecil W. Mann
Tulane University

Accelerative Forces

Some Characteristics of Vestibular Eye Movements 36
George R. Wendt
University of Rochester

Studies to Define Quantitatively the Stimulus Required to Produce Motion Sickness 42
Walter H. Johnson
Defence Research Medical Laboratories

Psychological Effects of Increased Positive Radial Acceleration 51
Neil D. Warren
University of Southern California

The Lag Effect Associated with Stimulation of the Semicircular Canals as Indicated by the Oculogyral Illusion 55
W. Brant Clark, San Jose State College
Capt. Ashton Graybiel, MC, USN, School of Aviation Medicine, Pensacola

The Effect of a Change in Direction of Resultant Force On Sound Localization: The Audiogravic Illusion 60
Capt. Ashton Graybiel, MC, USN and Jorma I. Niven
School of Aviation Medicine, Pensacola

Age As A Variable in Post-Rotational Phenomena 67
Frederick E. Guedry, Jr.
Tulane University

THEORETICAL

The Operating Principle of the Vestibular Mechanisms 73
Robert Mayne
Goodyear Aircraft Corporation

The Relation Between Visual and Postural Determinants of the Phenomenal Vertical 77
James J. Gibson
Cornell University

Some Studies of Visual Perception of Motion 81
William H. Ittelson
Princeton University

Summary 88
Capt. Ashton Graybiel, MC, USN and Cdr. Alan Grinsted, MSC, USN
School of Aviation Medicine, Pensacola

ATTENDANCE LIST

Office of Naval Research
Advisory Panel for Psychophysiology

Dr. H. K. Hartline, Johns Hopkins University, Baltimore, Maryland
Dr. H. Davis, Central Institute for the Deaf, St. Louis, Missouri
Dr. E. G. Wever, Princeton University, Princeton, New Jersey
Dr. S. Guild, Johns Hopkins Hospital, Baltimore, Maryland
Dr. C. H. Graham, Columbia University, New York, New York
Dr. C. Pfaffmann, Brown University, Providence, Rhode Island

Ex-Officio Members

Dr. Henry A. Imus, Office of Naval Research
Dr. J. W. Macmillan, Office of Naval Research
Dr. William Berry, Office of Naval Research

Consultants to the Panel

Dr. J. Q. Holsopple, Veterans Administration, Washington, D. C.
Dr. J. J. Gibson, Cornell University, Ithaca, New York
Dr. B. Clark, San Jose State College, San Jose, California
Dr. W. H. Ittelson, Princeton University, Princeton, New Jersey
Mr. Robert Mayne, Goodyear Aircraft Company, Akron, Ohio

University Representatives under contracts with the Office of Naval Research

Emory University, Atlanta, Georgia
Dr. Harlow W. Ades
Dr. Walter A. Mickle

University of Rochester, Rochester, New York
Dr. G. R. Wendt
Dr. G. T. Hauty

University of Southern California, Los Angeles, California
Dr. N. D. Warren

The Tulane University, New Orleans, Louisiana
Dr. Cecil W. Mann
Mr. F. E. Guedry, Jr.
Dr. F. McCord

U. S. Naval School of Aviation Medicine, Pensacola, Florida
Capt. Leon D. Carson, MC, USN, OinC
Capt. O. W. Chenault, MC, USN, Executive Officer
Capt. A. Graybiel, MC, USN, Director of Research
Cdr. A. D. Grinsted, MSC, USN
Lt. W. F. Madden, MSC, USN
Dr. H. J. Schaeffer
Dr. J. I. Niven
Miss Rosalie K. Amber

U. S. Naval School of Aviation Medicine, Pensacola, Florida (Cont'd)
S. I. Kemp
C. J. Atkinson

U. S. Naval Air Station, Pensacola, Florida
Capt. W. Dana, MC, USN, Naval Air Training Staff
Cdr. D. G. McKinnon, MC, USN
Arthur C. Poe, Jr., Naval Air Training Staff
R. A. Moore, U.S. Naval Hospital

U. S. Naval Air Station, Jacksonville, Florida
Capt. J. E. Early, MC, USN

U. S. Naval Bureau of Medicine & Surgery
Cdr. H. A. Smedal, MC, USN
Cdr. R. L. Christy, MC, USN
Lt. J. F. Snyder, MSC, USN

U. S. Aviation Medical Acceleration Laboratory, Naval Air Development Center, Johnsville, Pennsylvania
Capt. J. Q. Poppen, MC, USN

U. S. Naval Medical Research Institute, Bethesda, Maryland
Dr. J. P. Flynn

U. S. Navy Electronics Laboratory, San Diego, California
Dr. A. M. Small

ONR Special Devices Center, Sands Point, Long Island, New York
Dr. C. P. Seitz

Canadian Defence Research Laboratory, Toronto, Canada (RCAF)
Dr. W. H. Johnson

Institute of Aviation Medicine (RCAF), Toronto, Canada
Lt. R. A. Stubbs

British Joint Services Mission
Surgeon Cdr. E. James, RN
Wing Cdr. J. B. Wallace, RAF

FOREWORD

The Symposium on Psychophysiological Factors in Spatial Orientation, of which this is the complete report, was sponsored by the Naval Research Advisory Panel for Psychophysiology at the request of the Office of Naval Research. Captain Ashton Graybiel, MC, USN, Director of Research at the School of Aviation Medicine, U. S. Naval Air Station, Pensacola, Florida, who initiated the Navy's participation in research on these problems, organized the program and served as chairman. Captain Graybiel is one of the chief investigators on the effects of angular acceleration upon the Naval aviator and has done much to stimulate this research.

The purpose of the symposium was to review the results of current research, to exchange information, to discuss needs for further research, and to implement the practical application of knowledge of psychophysiological factors in spatial orientation to flight operations. The participants in the discussions were both civilian and military scientists interested in the disciplines of medicine, physiology, psychology, and engineering.

The assistance of Captain L. D. Carson, MC, USN, and Captain O. W. Chenault, MC, USN, of the School of Aviation Medicine in providing the space and equipment for the meetings, quarters and transportation for the participants, and a tour of the research facilities of the School, is gratefully acknowledged. Special thanks are extended to the scientists whose cooperation in presenting the papers and preparing condensations of them for inclusion in this report contributed significantly to the success of the symposium.

Henry A. Imus

Henry A. Imus
Head, Psychophysiology Branch
Office of Naval Research

U. S. NAVAL SCHOOL OF AVIATION MEDICINE
U. S. Naval Air Station
Pensacola, Florida

INTRODUCTION

SPATIAL DISORIENTATION IN FLIGHT*

Capt. Ashton Graybiel, MC, USN
U. S. Naval School of Aviation Medicine
Pensacola, Florida

INTRODUCTION

When a pilot takes off from the earth and, within limits, becomes free to fly about in space, he is confronted with unique problems in spatial orientation (1,2,3,4,5,6). He must be oriented with regard to the plane, the earth, and, sometimes, to other objects as well. The ability to orient himself simultaneously to plane, earth, and other objects is an acquired accomplishment and is subject to all the laws of learning and forgetting. Ordinarily this task is easy, but it may become difficult or even impossible under certain flight conditions. Loss of spatial orientation, more commonly termed spatial disorientation, may readily cause the pilot to make a wrong decision and this in turn lead to wrong action.

What follows is a limited review of the problem based on the specific sensory experiences involved. The discussion is divided into two parts, the first being concerned with spatial orientation and the second with spatial disorientation in flight.

Ashton Graybiel, a captain in the Navy Medical Corps, has been Coordinator of Research at the Naval School of Aviation Medicine, Pensacola, since 1945. Captain Graybiel received his B.A. and M.A. degrees from the University of Southern California and his M.D. from the Harvard University Medical School. After holding fellowships at University College Hospital, London, and Massachusetts General Hospital, he was a research associate at the Harvard Fatigue Laboratory from 1938 to 1945. He became an instructor in the Harvard Medical School in 1940 and two years later an instructor in cardiology at the Naval School of Aviation Medicine where he has conducted research in Aviation Physiology.

SPATIAL ORIENTATION IN FLIGHT

Spatial orientation may be looked upon as a phenomenon of perception which represents the individual's interpretation of stimuli originating in various organs of special sense. The relative importance of the various sense organs considered in terms of the pilot's task is indicated in Table 1. Emphasis is placed upon the role of the various sensory organs concerned and little attention is given either to central mechanisms which may influence the presentation of the perceptual data or its interpretation at the cognitive level. Proper perception depends on the functioning of many bodily mechanisms some of which are primarily psychological and some primarily physiological in character.

Orientation to the Plane

This is accomplished with the aid of all of the senses which are useful in orientation on the ground. Visual cues are plentiful unless they are deliberately reduced and provide all of the perceptual data necessary for orientation to the vertical and horizontal axes as well as to specific portions of the plane. The sensory receptors**, including the otolith organ, which respond either directly or indirectly to the force of gravity or acceleration, furnish an abundance of cues which normally orient the pilot to the vertical axis of the plane. Sensory elements concerned with kinesthetic perception are of importance in locating objects within the pilot's reach. Auditory space perception and the perception of rotation following stimulation of the semicircular canals are relatively unimportant.

---

*BuMed Project NM 001 059.01.25

**For economy in description the several sensory receptors which tend directly to orient one in the direction of gravity or resultant force are termed gravitational or G receptors and the perception of these stimuli are referred to as gravitational cues.

TABLE 1

Importance of Sense Organs for Proper Spatial Orientation in Flight

	Eye	G-Receptors		Semi-Circular Canals	Acoustic Labyrinth
		Otolith Organ	Other		
PLANE	Very Important	Moderate Importance	Moderate Importance	Nil	Very Slight Importance
EARTH	Essential	Occasional Slight Importance	Occasional Slight Importance	? Nil	Very Slight Importance
OBJECTS IN SPACE	Essential	Nil	Nil	? Nil	Very Slight Importance
*	Essential	Slight Importance	Slight Importance	? Nil	Very Slight Importance

*Simultaneous orientation to plane, earth, and objects in space

The global effect of these sensory cues, functioning harmoniously in coordinated flight, is literally to anchor the pilot to the plane; they comprise his strongest sensory experiences hence orientation to the plane is relatively easy compared with orientation to the earth and other objects. Indeed, the task is so easy that it has escaped emphasis in discussions of this kind. However, the very fact that the plane forms such a strong frame of reference renders the pilot more susceptible to disorientation with regard to the earth and deserves emphasis for this reason if no other.

Orientation to the Earth

This might be considered from the standpoint of (a) geographical localization, (b) estimation of altitude, (c) estimation of relative speed, and (d) attitude of the plane in relation to the horizon; the last is the only aspect to be considered at this time.

By the use of special equipment it would be possible for the pilot to perceive the relation of plane to horizon on the basis of auditory or kinesthetic cues. However, such equipment is not in use partly because of technical difficulties but chiefly because it is inferior to methods involving visual cues. Orientation to the horizon is possible on the basis of gravitational cues during level unaccelerated flight because the attitude of the plane coincides with that of the horizon. However, this is of small positive value inasmuch as level flight cannot always be maintained. Thus, under present-day flight conditions visual cues are essential. Ordinarily there is visual reference to both plane and horizon but the dual orientation could be accomplished on the basis of orientation to plane by means of gravitational cues alone and orientation to horizon by means of visual cues; thus, visual and gravitational determinants would be unified in a single perceptual whole. Instrument flight was developed in order to provide the pilot with indirect visual cues when visual contact with the horizon could not be made.

Inasmuch as the position of the pilot and plane may have a changing relation to the horizon during flight, certain dynamic aspects of the task must be considered. Because of the strong sensory cues binding the pilot to the plane, the natural tendency would be to regard the plane as fixed and the horizon as the changing reference point. Some experience is required before the plane is regarded as moving in relation to a fixed horizon. It is worthy of passing notice that the gyrohorizon, which is standard equipment on most planes, shows the plane as the stationary and the horizon as the moving reference. Some confusion would be prevented if this were reversed.

Orientation to the earth involves much more than a knowledge of the attitude of the plane in relation to the horizon. This is particularly true during take-offs and landings where depth perception, estimation of relative speed, and other factors are of great importance.

Orientation to Various Objects in Space

Vision is essential for proper orientation to such objects as heavenly bodies, clouds, airplanes, etc. A very small contribution is sometimes made on the basis of sound localization in the case of airplanes, radiation effects in the case of the sun, etc.

Sometimes, flying in formation the pilot is concerned only with orientation to another plane but, ordinarily, orientation to objects cannot be considered apart from orientation to the entire structure of things in space. The dynamic aspects differ greatly depending on the nature and number of objects in the visual field and their relationship to plane and earth. A pilot regards celestial bodies as fixed points of reference just as in the case of the horizon. He usually regards nearby clouds as stationary in respect to himself and distant clouds may be used in orientation to the horizon. A nearby plane may be regarded either as moving or fixed in relation to the pilot's own plane, or both may be regarded as moving in relation to the earth.

Simultaneous Orientation to Plane, Earth and Other Objects in Space

Under certain circumstances the pilot's task consists of fusing plane, earth, and other objects into a single arrangement in space. For purposes of discussion this task will be considered from the standpoint of the sensory perceptions per se and the interpretation of these perceptions at the cognitive level. Although the total sensory experience is based on cues from several sources, visual and gravitational cues are so important that it is scarcely an oversimplification to neglect the others in the present discussion. A comparison between the two affords the best appreciation both with regard to their positive contribution to spatial orientation and their role in causing disorientation.

Visual cues are absolutely essential; without them orientation to earth and other objects would be impossible under present flight conditions. The physical stimulus for vision acts at a distance and vision may be independent of body position and of the direction of gravity or resultant force. Vision is under a great deal of voluntary control; thus we can shut out all stimuli by closing the eyes and within limits can direct the line of regard. Visual cues are never forced upon us but, with eyes open, we must accept whatever is in the visual field. The important problem is to ensure adequate visual perception in flight and our experience in ordinary life forms a useful basis for its interpretation.

Gravitational cues are not essential for spatial orientation in flight but are continually forced upon us. There is no way in which they can be excluded as in the case of vision. Although the force of gravity or acceleration may act at a distance it does so by virtue of our direct contact with the environment. Thus the direction of the force and our body position are the important determinants. In ordinary life gravitational cues orient us to the earth but must not be used for this purpose in flight where they are only useful for orientation to the plane.

It is apparent therefore that the pilot may use his total sensory experience for orientation to the plane but only his visual perception for orientation to the earth and to other objects. This does not imply a conflict between sensory stimuli either at or below the level of perception but rather a choice on the part of the flyer. He becomes disoriented not because he recognizes gravitational cues but because he uses them improperly.

The task of orientation in space may be complex and difficult. The circumstances are often dynamic with rapid shift of scene and point of reference. This calls for continual reorientation based on quick shifts in visual attention between plane, earth, and other objects. At fast speeds there is little time to resolve sensory stimuli into a correct and complete pattern of spatial perception. Anticipation then becomes important and much training and experience is necessary before adequate facility is acquired.

SPATIAL DISORIENTATION IN FLIGHT

Spatial disorientation during flight may occur as the result of pathological changes in various bodily systems but it may also occur in the absence of any pathological change and when all of the sense organs concerned are functioning normally. In the discussion which follows it will be assumed that pathological factors are not involved.

The relative importance and interrelationships of the various sensory organs in causing spatial disorientation are indicated in Figure 1. The two most important factors are visual perception and G perception with the others occupying much less important positions. These factors may act directly to cause disorientation or may act indirectly through their influence on each other.

Kinesthetic perception plays a relatively small role; it is intimately related to G perception and may be directly responsible for spatial disorientation. Auditory space perception is strongly influenced by stimuli from the semicircular canals (7), G receptors (8) and vision but the reciprocal influence is slight or nil; it plays a small role in causing spatial disorientation.

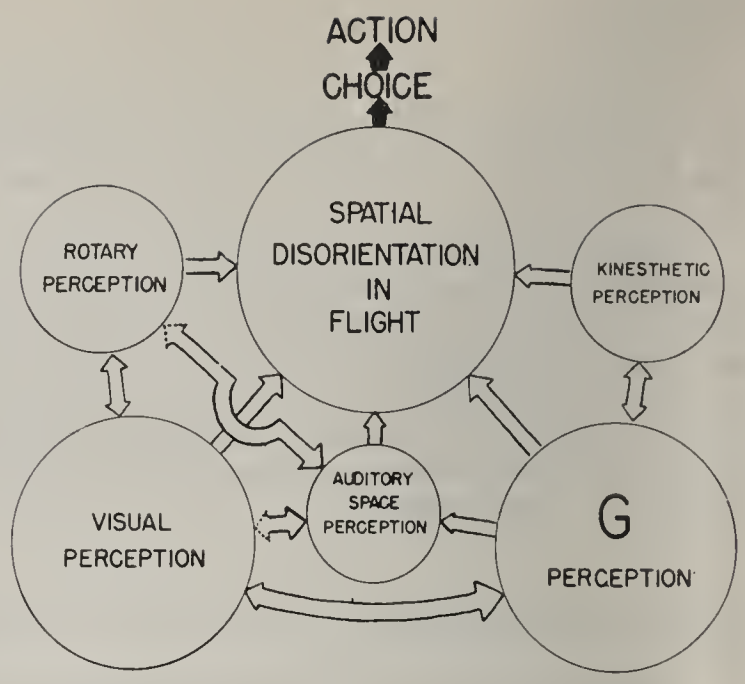

Figure 1 - Sensory perceptions and their interrelationships which may contribute to spatial disorientation

The Semicircular Canals

Flyers are frequently subjected to angular accelerations many times greater than the threshold values for stimulation of the semicircular canals (9). The effects of stimulation may cause disorientation in three ways: first, by its influence on visual perception, second, by producing apparent feelings of rotation and dizziness, and third, by influencing sound localization.

Stimulation of the sensory elements in the semicircular canals influences visual perception because of the reflexly-produced ocular nystagmus. The eye movements themselves are not perceived. Visual perception during the fast phase is disregarded but not during the slow phase. The tracking of the image across the retina is perceived as movement of objects in the visual field rather than of the eye. Thus, an object stationary with respect to the observer may appear to drift across the visual field; this phenomenon has been called the oculogyral illusion; darkness favors its appearance whereas if visual cues are plentiful the illusion is reduced or abolished.

It is difficult to evaluate the practical significance of this illusion in flying. The angular decelerations produced in coming out of some spins are sufficient to cause a blurring of vision under any circumstance. Even moderate stimulation would create an illusion of movement if objects were viewed in the dark or against a uniform background. The difficulty in evaluating the significance of the oculogyral illusion rests partly on the fact that the flyer cannot distinguish between real and apparent movement.

The two best means of preventing the oculogyral illusion are to provide a good visual framework and to avoid sudden recovery from a maneuver in which the plane rotates about one of its axes for a relatively prolonged interval. The latter takes advantage of a lag effect associated with stimulation of the canals (10).

The apparent feelings of rotation and dizziness induced by stimulation of the semicircular canals (11,12) are unimportant causes of disorientation. The same is true for the effect of stimulation of the canals on sound localization (7).

The Otolith Organs and Other Sensory Elements Concerned in Orientation to Gravity

The G receptors, which are stimulated by the force of gravity and by rectilinear accelerations, play a very important role in causing spatial disorientation. Several different mechanisms may be involved.

The single most important cause of disorientation is due to the fact that in ordinary life gravitational cues are used for orientation to the earth whereas in flight they can only be relied upon for orientation to the plane. The flyer cannot abolish these cues; he must refrain from making the assumption

that his orientation to the plane cues him to the horizon, however natural it would seem to do so. The very fact that a pilot is well oriented to the plane places him under the circumstance of being potentially disoriented to the horizon. Disorientation is based on loss of adequate visual cues on the one hand and the presence of gravitational cues on the other. Whenever visual cues become inadequate the pilot loses his basis for correct orientation. In this circumstance there is a strong and natural tendency to base orientation to the earth on gravitational cues and the error will be equal to the angle between the direction of gravity and of resultant force.

There is another cause for disorientation which is due to the direct influence of gravitational cues on visual perception. This has been termed the oculogravic illusion (13) and may be observed when the direction of resultant force is not in the vertical axis of the plane. In this circumstance gravitational cues will orient the pilot to the direction of resultant force and objects in the visual field will appear to move and to assume new positions in space to conform with the direction of G. If the force of acceleration is weak, the visual cues may prevent the illusion but, if strong, the gravitational cues seem to overwhelm the visual cues and the illusion is both curious and striking. Engine failure in high speed planes would present an extreme example of a sudden change in direction of resultant force. Fortunately, the time involved is so short that the natural lag in the development of this illusory phenomenon (14) prevents its full exhibition.

Gravitational cues also effect sound localization and kinesthetic perception but here their role is small.

The Eye

Inadequate visual perception may be responsible for spatial disorientation on the basis of the physical stimulus per se, the influence of other sense organs, and the effect of central factors on visual perception. The important determinants in addition to the perceptual data per se include the pattern or rhythm associated with its presentation, symbolic cues which have special meaning, and the mental set and experience of the individual.

Visual perception may become inadequate for proper spatial perception due to inadequate perceptual data. There are many causes for this centering around (a) celestial factors such as darkness, brightness of sun, etc., (b) atmospheric conditions such as rain, fog, etc., (c) inadequate visual framework and (d) factors relating to the plane such as small size of windows, glare, etc. The influence of stimuli from other sensory organs has been mentioned above in describing the role of the semicircular canals and the G receptors. Finally it should be mentioned that a person tends to perceive things in a manner which accords with his past experience and there is a possibility that in this interpretation a cause for disorientation may be found.

The factors responsible for spatial disorientation in flight may be summarized in terms of the pilot's task. Disorientation with regard to the plane is relatively uncommon. Errors in the manipulation of controls may be traced to errors in kinesthetic perception. Visual perception of the instruments may be inadequate if strong angular accelerations produce ocular nystagmus. A false feeling of being tilted in relation to the plane would result if there is a considerable angle between the vertical axis of the plane and the direction of resultant force.

Disorientation in regard to the earth may be due to loss or reduction of visual cues on the one hand and the presence of gravitational cues on the other. The substitution of indirect for direct visual cues while invaluable is not perfect and introduces new problems both at the level of visual perception and at the higher level of judgment and choice.

Disorientation with regard to various objects in space can be traced to inadequate visual perception. This may be due to inadequate physical stimuli, or to the influence of other sensory organs, visual perception, or both.

Spatial disorientation may lead the pilot to make a wrong choice and this in turn lead to wrong action. Under certain circumstances at least, wrong action would result in an accident with consequent injury and loss.

* * *

REFERENCES

1. Holsopple, J. O. (C. C. Murchison, editor), "Foundations of Experimental Psychology," (1st ed) Ch. X, Worcester: Clark University Press, 1929

2. MacCurdy, J. T., "Disorientation and Vertigo, with Special Reference to Aviation," Brit. J. Med. Psychol. 25:42, 1934-35

3. Alpers, B. J., "Vertigo: Its Neurological Features," Tr. Am. Acad. Ophth. 46:38, 1941

4. Armstrong, H. G., "Principles and Practice of Aviation Medicine," (2nd ed) Baltimore: The William and Wilkins Co., 1943

5. Graybiel, A., "Disorientation in Pilots," Contact 5:412, 1945

6. Vinacke, W. E., "Illusions Experienced by Aircraft Pilots While Flying," J. Aviation Med. 18:308, 1947. See also BuMed Research Project X-148 (Av-4-3), Report No. 9, 31 May 1948

7. Clark, B., and Graybiel, A., "The Effect of Angular Acceleration on Sound Localization: The Audiogyral Illusion," BuMed Research Project X-148 (Av-4-3), Report No. 21, 2 July 1948

8. Graybiel, A., and Niven, J. I., "The Effect of a Change in Direction of Resultant Force on Sound Localization: The Audiogravic Illusion," BuMed Research Project Report NM 001 059.01.23, 10 March 1950

9. Graybiel, A., Kerr, W. A., and Bartley, S. H., "Thresholds of the Semicircular Canals," Amer. J. Psychol. 61:21, 1948. See also BuMed Research Project X-148 (Av-4-3), Report No. 17, 12 March 1947

10. Clark, B., and Graybiel, A., "The Lag Effect Associated with Stimulation of the Semicircular Canals as Indicated by the Oculogyral Illusion" (in preparation)

11. Graybiel, A., and Hupp, D. I., "The Oculogyral Illusion: A Form of Apparent Motion which May Be Observed Following the Stimulation of the Semicircular Canals," J. Aviation Med. 17:3, 1946. See also BuMed Research Project X-148 (Av-4-3), Report No. 4, 1 November 1945

12. Graybiel, A., Clark, B., MacCorquodale, K., and Hupp, D. I., "The Role of Vestibular Nystagmus in the Visual Perception of a Moving Target in the Dark," Amer. J. Psychol. 59:259, 1946. See also BuMed Research Project X-148 (Av-4-3), Report No. 5, 14 January 1946

13. Graybiel, A., "The Oculogravic Illusion" (in preparation)

14. Graybiel, A., and Brown, R. H., "The Delay in Visual Reorientation Following Exposure to a Change in Direction of Resultant Force on a Human Centrifuge," U. S. Naval School of Aviation Medicine and Research and Tulane University, Project NM 001 037, Joint Report #3, May 1949

EXPERIMENTAL

NEUROPHYSIOLOGICAL FACTORS

ANATOMY AND PHYSIOLOGY OF THE VESTIBULAR SYSTEM*

Harlow W. Ades
Emory University
Atlanta, Georgia

I am to talk about the anatomy and physiology of the vestibular end organs and their central connections. The over-all problem, however, has to do with the sense of position and motion, the adjustments of position, and the modifications of movement which may take place as a result of such stimulation. Ultimately we are interested in the distortion of such experience and the reactions under abnormal conditions of motion and acceleration. It would be a mistake, therefore, to forget in our absorption with the vestibular system that this sense organ and its projection in the brain stem, spinal cord, cerebellum, and cerebral cortex represent only a part of the sensory equipment responsible for the reporting of static or changing position which makes possible rapid modifications of motor activity and postural adjustment to meet changing conditions. This is perhaps best illustrated by the old experiment of Bard on the righting reflex of the cat. You may recall that the essential technique in his experiment was that of motion picture photography of the cat, which was dropped a short distance to a flat surface from an originally supine position.

Harlow W. Ades attended the University of Illinois where he received his B.S., M.S., and Ph.D. degrees. He has held research and teaching positions in zoology and psychology at the University of Illinois and was an assistant in physiological optics at Johns Hopkins University. In 1939 he became affiliated with Emory University and is now Chairman of the Department of Anatomy. Dr. Ades was the Annual Research Professor of Neurology at the Institute of Neurology, Northwestern University in 1947-48.

The films of a normal cat, projected slowly, show that the essential activity of righting is not a rapid flipping over of the entire body simultaneously, but instead, consists of a kind of spiral turning through 180°, beginning, as it appears in the films, almost with the tip of the nose and progressing to the tip of the tail. An animal which had been blindfolded was able to accomplish this movement quite well. An animal in which the vestibular end organs had been destroyed could also accomplish the movement, though it required more time than the normal - that is, greater distance of fall to carry righting to completion. Animals which were both blind and whose vestibular end organs had been destroyed were entirely unable to initiate the righting response when dropped from a supine position; they fell flat on their backs. However, if these animals were held supine except for the head, which was twisted to one side, they were able to carry through the rest of the spiral motion of righting and to land on their feet.

The interpretation of this seems to be that both visual and vestibular reflexes are concerned and important in the normal righting reaction, although neither is absolutely essential so long as the other is functioning. But if the head position is properly adjusted, even in the absence of these sense organs, the remainder of the righting reaction - that is the righting of neck, trunk and tail - can still be accomplished. The manner in which this is done suggests that a kind of train reaction is set up in which the turning of the head puts the muscles of the neck under tension. The response to this stimulus is an adjustment by these muscles toward the head position which, in turn, places the muscles of still more caudal segments under tension, stimulation of which sets off a similar reaction and so on back until the entire body has been turned through 180°.

---

*ONR Project NR 140-916, Contract N9onr-87800

Such an activity, as you think of it, calls into play large numbers of sensory elements, principally, we would presume, muscle and joint sense organs, stimulation of which in turn evokes the activity of large and widely separated areas of the central nervous system, including both segmental and suprasegmental mechanisms. This so modulates the discharge of motor systems as to bring about an economical modification of postural tone to suit the compulsion of the cat to land on his feet.

Consideration of this kind of experiment leads to a concept of the vestibular system as only one part, albeit a highly specialized one, of the entire proprioceptive system, which itself has meaning only as it is expressed in subjective experience, or in the complex modification of tonus of many muscle groups which we call postural adjustment.

With this reminder of the complexities of posture and the enormous and constant devotion of vast areas of the nervous system to its adjustment to meet changing conditions of movement, of acceleration, and of gravity, I shall turn to the vestibular system and devote most of my time to it as being of particular interest because of its specialization in the recording of rotary and accelerative movement, especially as these are related to head and eye position.

The vestibular end organ consists of a system of membranous canals, and enlargements thereof, filled with endolymph and encased in the petrous bone. It is surrounded by perilymph and is connected with the outside only secondarily by way of the perilymphatic vestibule whose hydrostatics can be influenced by the action of the stapes in the fenestra ovalis, although the vestibular organs seem to be relatively refractory to such stimulation. The remainder of the membranous labyrinth consists of the cochlear duct surrounded by its extension of the perilymphatic vestibule, the scala tympani, and the scala vestibuli. We are concerned for the moment only with the nonacoustic portion of the membranous labyrinth which consists of three semicircular canals, the utricle, and the saccule. The canals are arranged at right angles to each other, representing three planes of space. At one end of each canal there is a dilation, the ampulla, containing a patch of sensory epithelium, the crista ampullaris. The utricle and saccule also have each an essentially similar patch of sensory epithelium called, respectively, the macula utriculi and the macula sacculi. These two together constitute what is called the otolith organ, because, unlike the cristae ampullaris, the hair cells of the maculae are overlain by and embedded in a gelatinous mass containing small calcareous crystals.

The adequate stimulus for any of these end organs seems to be movement of the endolymph which displaces the ciliate tufts of the hair cells. However, as will be seen later, the sensory cells, or some of them, apparently discharge slowly but regularly even in the absence of movement, the frequency increasing when movement begins.

The sensory cells of both maculae and cristae are columnar epithelial cells, each containing a projecting tuft of hairs or cilia. They are otherwise distinguished from ordinary columnar epithelial cells by a pericellular basketwork of dendritic endings from the peripheral processes of the cells of Scarpa's ganglion. This is the sensory ganglion of the vestibular end organ and it lies at the distal end of the internal auditory meatus. The cells of this ganglion, like those of the acoustic ganglion, and those of the retina, are bipolar. Their central processes or axones collectively constitute the vestibular portion of the eighth cranial nerve, joining the similar processes from the cochlear or acoustic portion of the inner ear to form the nerve.

The terminations of the vestibular axones are found in a complex of nuclei occupying an extreme lateral and superior position, extending from the middle to the caudal part of the pons. A small component of the afferent fibers from Scarpa's ganglion bypasses the vestibular nuclei to go by way of the restiform body to direct terminations in the cerebellar cortex.

Let us consider the vestibular nuclear complex first. While there is no appreciable geographic separation between the component parts, they are distinguishable from each other on the basis of cell-type arrangement and destination of second-order fibers. There is a large medial vestibular nucleus, the nucleus of Schwalbe; a smaller superior and rostral portion, the superior vestibular nucleus of Bechterew; a lateral portion, the lateral vestibular nucleus of Deiters; and finally, the most caudal part of the complex, the spinal vestibular nucleus. The principal pathway of second-order vestibular fibers is a tract running longitudinally through the brain stem from midbrain to cervical cord in a medial position just under the floor of the fourth ventricle, the aqueduct, and the central canal of the cord. This is the medial longitudinal fasciculus. While it appears anatomically as a compact bundle running through a considerable extent of stem and cord, its component fibers actually join and leave the tract at many different levels.

The medial nucleus of the vestibular complex sends axones to join the contralateral medial longitudinal fasciculus, running both rostrally and caudally, so that some of them are distributed to the eye muscle nuclei and the reticular nuclei of the midbrain, and the rest are distributed to the reticular formation of the pons and medulla and to the anterior horn of the cervical cord. The superior nucleus of Bechterew gives off second-order fibers, some of which join the ipsilateral medial longitudinal fasciculus to ascend to terminations similar to those of the contralateral ascending components from the medial nucleus. Other second-order fibers leave the superior nucleus and join the direct vestibulo-cerebellar fibers to pass through the restiform body and terminate with them in the median part of the cerebellar cortex. Contralateral descending fibers arise from the cells of the lateral nucleus to descend in the opposite medial longitudinal fasciculus. The spinal nucleus apparently gives no second-order fibers to the medial longitudinal fasciculus, but instead sends fibers downard as the lateral vestibulo-spinal tract through the cervical cord to terminations in lower parts of the cord. As will be indicated in a subsequent contribution to this Symposium, the spinal nucleus also appears to send second-order fibers to ascend contralaterally with the medial lemniscus as the beginning of the vestibular cortical projection pathway. We know no more of the pathway of cortical projection than this until we reach the actual area of cortical termination; the intermediate course and relays remain to be found.

The terminations of the ascending portion of the medial longitudinal fasciculus are in the nuclei of the oculomotor, trochlear and abducens nerves, as well as in the interstitial nucleus of Cajal and the nucleus of the posterior commissure, otherwise known as the nucleus of Darkschewitsch. It should be pointed out here that these nuclei also contribute descending fibers to the medial longitudinal fasciculus and provide relay connections with the roof of the midbrain, which itself has much to do with reflex adjustment of head and eye positions to both visual and auditory stimulation. The foregoing are the most obvious courses and terminations of fibers of the medial longitudinal fasciculus; however, they are not the only ones.

Of scarcely less importance, particularly to a group which is interested in motion sickness, either independent second-order fibers or collaterals from the medial longitudinal fasciculus filter off in considerable numbers into the reticular formation of the pons and medulla. These are of special interest as the most likely pathway for establishing close reflex connections with the vagal complex and may, therefore, be important in the integration of the visceral manifestations consequent on the overstimulation of the labyrinth.

Before we leave the anatomy of the vestibular system, it should be noted that not only does the cerebellum receive both first- and second-order fibers from the ganglion of Scarpa and the superior vestibular nucleus respectively, but it in turn projects to the fastigial nuclei of the cerebellum, which send fibers by way of the fastigiobulbar and uncinate bundles to complete a circuit by terminating again in the vestibular nuclei, and probably in the reticular formation of the pons and medulla. This alone would serve to distinguish the vestibular from most other sensory nuclei of the brain stem, for which we know of no similarly intricate system of reciprocal interconnections with suprasegmental structures. Exactly what the significance of this is one cannot say with certainty. It may, among other things, help to account for the nystagmus and other characteristically vestibular signs one sometimes sees as a sign of cerebellar injury.

To sum up, then, we see in the vestibular system an anatomical arrangement of first- and second-order fibers, with certain side excursions which closely links the vestibular input with two or three kinds of efferent mechanisms. The most apparent, if not the most important of these, is the complicated midbrain mechanism for the control of eye movements. The second is the strong caudal projection to the cervical cord from which, in turn, flows the motor innervation of the neck muscles. These mechanisms constitute, collectively, a system of reflex connections which have few synapses between the sense organs and the final common path, and are, therefore, capable of bringing about rapid adjustments of head and eye positions in response to labyrinthine stimulation. Moreover, the pattern of interconnection is such that a high degree of integration is possible, so that, although stereotyped, the resultant responses are very precise and economical. Pathways for similar adjustments of head and eye positions in response to visual or auditory stimulation, and interconnections of these with vestibular centers are closely integrated with the vestibular reflex system and utilize closely similar and often identical tracts. Finally, there are the less obvious, but perhaps no less important, pathways by which reflex connections are made with motor nuclei of the lower brain stem through the reticular formation.

Direct studies of the details of vestibular function from a neurophysiological standpoint have been meager. There are two recent studies of discharges from vestibular receptors in the cat and in fish. Löwenstein studied the discharge of an isolated nerve from the horizontal canal of the dogfish. He observed a resting discharge which changed in frequency upon rotation. With still more isolated groups of fibers, he also studied responses from the nerve of the saccule with similar results. Adrian, in 1943, studied the impulses in the region of the vestibular nucleus of the cat and identified two types of response: (a) gravity controlled discharge, which depended only on position of head in space and (b) angular acceleration (i.e., horizontal rotation) which gave discharges near the oral border of the striae acusticae. Lateral tilt and transverse rotation gave responses near the aboral border. The gravity receptors were stimulated increasingly by tilt and also reacted to any acceleration. In either case, a slow adaptation was observed, such that quick turns yielded a quick burst of activity, but constant acceleration caused a discharge which lasted approximately 25 seconds and then ceased, followed by a similar discharge upon deceleration.

In Adrian's preparations, it is important to note that there is a constant low-frequency response at rest, which may be either suppressed or increased in frequency, depending upon the stimulus situation. Consequently, it would be improper to think of the vestibular system as one in which response is proportionate to stimulation. This would be borne out by the more recent studies of B. E. Gernandt. The remaining evidence of vestibular function, as it has been studied neurophysiologically, falls into two categories which, one may suspect, are only superficially unrelated.

Bach and Magoun confirmed a previous hypothesis that injury in the region of the vestibulospinal tract of cats abolishes the spasticity of decerebrate rigidity, an example of the so-called "release phenomenon" of hyperactivity of the spinal cord after decortication. They found that destruction of the vestibular nuclei does not play a major role in release of the spasticity, but injuries to certain parts of the pontine tegmentum and reticular formation are of the greatest importance in release of the spasticity of the decerebrate.

Mettler, in 1940, demonstrated that removal of the major part of the heads of both caudate nuclei has profound effect upon the symptoms derived from subsequent vestibular injury. To illustrate, animals which have undergone complete bilateral labyrinthectomy show a crouching posture and dyskinesia. These symptoms can be alleviated by subsequent removal of the head of the caudate nucleus. Furthermore, animals normal except for caudate lesions, showed less effect of rotation with markedly shorter periods of postrotatory nystagmus and forced posture.

These studies are only a beginning in the accumulation of knowledge of the detailed functioning of the vestibular system. Nevertheless, they suggest most strongly that the problem of orientation in space is only partly vestibular, and that what we must do is discover how vestibular stimulation is integrated with that of other postural sensory mechanisms, and how these in turn are utilized in normal subjective experience and motor adjustment to meet postural change. There is increasing evidence, both functional and anatomical, of close interdependence between vestibular, proprioceptive, auditory, and visual systems on the one hand, and extrapyramidal discharge systems on the other.

* * *

CORTICAL PROJECTION OF POSTURAL IMPULSES*

Walter A. Mickle, Jr., and Harlow W. Ades
Emory University
Atlanta, Georgia

Application of the methods of electrical neuronography has been made to the study of some of the systems which are concerned with posture and spatial orientation. These examinations have included the auditory, vestibular, proprioceptive, and tactile systems, particularly in regard to their cortical projection.

Walter A. Mickle, Jr. received his B.S. from Guilford College and his M.A. from Duke University. Further graduate work was interrupted in 1942 when he became Research Bacteriologist with the Army Epidemiological Board. Commissioned in the Army in 1944, he was assigned to the Commission on Acute Respiratory Diseases at Fort Bragg. Following release from active duty, he completed the requirements for his M.D. at Emory University where he is now Assistant Professor of Anatomy.

EXPERIMENT

Young adult cats and a few kittens have been used. These animals were prepared by appropriate surgical exposures while under nembutal anesthesia, and stimuli were applied at various positions within the nervous system. In the case of the auditory system, a click from an earphone was used as a stimulus; for all others electrical pulses were used. The pulses used for activation of the earphone or direct stimulation were square waves of 0.1 ms duration and of intensities just sufficient to elicit a maximal response. These stimuli were triggered by the cathode-ray oscillograph sweep circuit and were repeated at approximately 1 second intervals. Potentials evoked on the surface of the cortex were picked up by a 0.5 mm ball-shaped silver monopolar exploring electrode, operating in conjunction with an indifferent electrode consisting of a cadmium-plated clip attached to exposed muscle. The potentials were amplified and the resulting pattern photographed from the cathode-ray oscillograph.

Direct electrical stimulation was performed with an insulated concentric electrode, the outer sheath of which was a 23-gauge hypodermic needle. Stimulating pulses were delivered through an isolation transformer, thus preventing either pole of the electrode from being in common with the grounded animal. Such an arrangement was used to limit the area stimulated.

Surgical approach to the nuclei of cuneatus and gracilis and the IVth ventricle was made posteriorly by aspiration of most of the cerebellum. The vestibular nerve was exposed by microdissection of its canal in the petrous bone, using a lateral approach. Stimulation of the dorsal funiculi of the cord and of the dorsal root ganglia was made through laminectomy, exposing the cord at various levels.

RESULTS

Click stimulation applied either monaurally or binaurally resulted in cortical response both in the primary acoustic projection area of the middle ectosylvian gyrus, and in a part of the anterior ectosylvian and anterior suprasylvian gyri of the cat. This anterior area is outside that usually recognized as either primary or secondary auditory projection and includes an area described by Tunturi (3) and called by him, a third auditory area. Responses in this anterior area have been positive monophasic spikes with a latency similar to those of the primary area, i.e., 7-10 ms. These responses

*ONR Project NR 140-916, Contract N9onr-87800

were anatomically separated from the primary auditory area by a narrow strip of the anterior ectosylvian gyrus in which responses were either absent or small and diphasic in sign. Cortical response in the anterior area is not affected by extirpation of the entire middle and posterior ectosylvian gyri.

Stimulation of the vestibular nerve alone through a minute fenestration resulted in the activation of a strip of cortex composed of the anterior bank of the anterior ectosylvian gyrus and the posterior bank of the anterior suprasylvian gyrus. This area had previously been shown to be responsive to aural stimulation. Responses to vestibular stimulation were found in this area alone and no activation of primary or secondary auditory areas was seen. The evoked potentials were positive and monophasic or were followed by a very low negative after discharge. They were of 300-500 μv amplitude and appeared with a latency of 5.5-7.5 ms. The response was almost totally contralateral to the side stimulated. It was found to be fairly sensitive to increasing depth of anesthesia, appearing best at levels somewhat lighter than are common in most other types of evoked potential experiments. At present, attempts at demonstration of the course of these impulses to the cortex have indicated only that they are conveyed within or near the medial lemniscus.

Activation of the proprioceptive system has been accomplished by three methods. Stimulation of the nuclei of cuneatus and gracilis by electrical pulses has been found to evoke potentials both in the primary somesthetic area and in the inferior portion of the anterior ectosylvian and suprasylvian gyri. These responses have been similar in sign and in latencies of 5-7 ms. An inactive strip of cortex has usually been found separating the two. In both cases responses have been almost totally contralateral to the stimulus.

The dorsal funiculi have been stimulated near the midline of the cord in the cervical, upper thoracic, and upper lumbar areas. In each case, two fields of reactive cortex were found, corresponding more or less identically with those demonstrated by nuclear stimulation described in the preceding paragraph. Latencies in each area of response have been the same, 7-10 ms, depending in part upon the level of cord stimulation. Stimulation of the dorsal funiculus on one side, however, yielded a bilateral cortical response, as contrasted with nuclear stimulation which was only contralateral. It has been noted that the primary somesthetic area is more sensitive, in the cat, to increasing depths of anesthesia; under very deep anesthesia it has sometimes not been seen, while the second area still responds well.

Incomplete experiments in which stimuli have been applied to dorsal root ganglia by electrically induced muscle twitch and by manual touching of the foot pads have been found to activate the same general cortical fields that are seen on posterior funicular or nuclear stimulation. In each case, the cortical response is bilateral.

CONCLUSION

These findings demonstrate, in the cat, a general cortical area composed of the tissue on both sides of the anterior suprasylvian sulcus, which is responsive to auditory, vestibular, proprioceptive, and probably tactile stimuli (Figure 1). The responses to each have some of the characteristics of a primary projection, especially in their latencies, which have been, in each case, no longer than those of the primary auditory or somesthetic areas. In the case of the vestibular system, as with the others, this latency is of such brevity as to be accounted for only by direct projection from the sensory thalamic nuclei.

The cortical projection to this area of each of these types of stimulation has been previously reported. Tunturi (3) described a similar cortical field in the dog which was responsive to auditory stimuli. Adrian (1,2), Woolsey (5,6), and Woolsey and Wang (7) have defined a second somesthetic area, and Walzl (4) reported the projection of vestibular impulses to a similar cortical area in the cat.

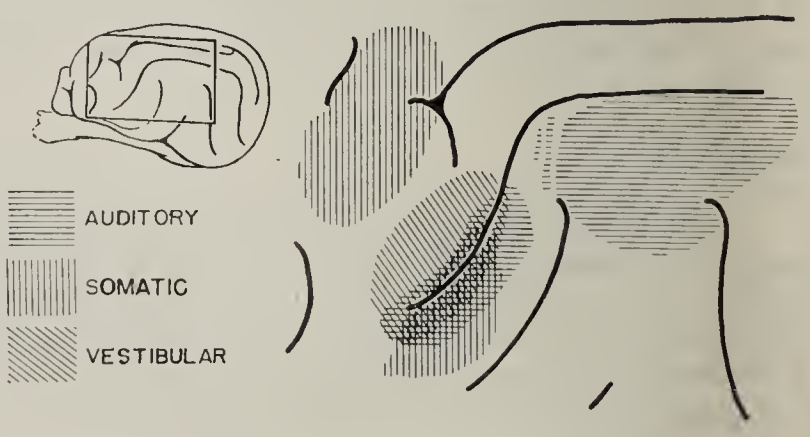

Figure 1 - Specific sensory projection areas and composite sensory projection area in the cerebral cortex of the cat

It appears, however, that the findings of these authors have not been viewed in conjunction. The demonstration of a polysensory area, with the characteristics of a primary projection, subserving several sense modalities which are concerned with posture and spatial orientation, strongly suggests that it may be a primary area of correlation.

* * *

REFERENCES

1. Adrian, E. D., "Double Representation of the Feet in the Sensory Cortex of the Cat," J. Physiol. 98:16, 1940

2. Adrian, E. D., "Afferent Discharges to Cerebral Cortex," J. Physiol. 100:159-191, 1941

3. Tunturi, A. R., "Further Afferent Connections to the Acoustic Cortex of the Dog," Am. J. Physiol. 144:389-394, 1945

4. Walzl, E. M., and Mountcastle, V. B., "Projection of the Vestibular Nerve to the Cerebral Cortex of the Cat," Am. J. Physiol. 159:595, 1949

5. Woolsey, C. N., " 'Second' Somatic Receiving Areas of Cat, Dog and Monkey," Fed. Proc., Am. Soc. Exptl. Biol. 2:55, 1943

6. Woolsey, C. N., "Additional Observations on a 'Second' Somatic Receiving Area in the Cerebral Cortex of the Monkey," Fed. Proc., Am. Soc. Exptl. Biol. 3:53, 1944

7. Woolsey, C. N., and Wang, G. H., "Somatic Sensory Areas I and II of the Cerebral Cortex of Rabbit," Fed. Proc., Am. Soc. Exptl. Biol. 4:79, 1945

ORIENTATION TO VISUAL AND POSTURAL VERTICAL*

INDIVIDUAL DIFFERENCES IN MODE OF SPACE ORIENTATION

Herman A. Witkin
Brooklyn College
Brooklyn, New York

Herman A. Witkin attended New York University where he received his B.A., M.A., and Ph.D. degrees. From 1940 to the present time he has been on the staff of Brooklyn College, first as an instructor and now as an assistant professor. In 1943-45 he was a Fellow in psychology of the National Research Council.

INTRODUCTION

The work to be described here was carried out during the past three and a half years under an ONR contract; it is part of a systematic research program that has been in progress in the psychological laboratories of Brooklyn College since 1942.

A brief review of some of our earlier investigations will help explain the origin of the problems with which this report is concerned.

Our very first studies attempted to determine the factors responsible for the maintenance of proper orientation toward the upright in space. The ability to establish the upright as quickly and effectively as we ordinarily do is based upon the stable and compelling representation of the upright in our surroundings, and upon our possession of adequate sensory equipment for its detection. First, the direction of gravity, which corresponds to the true upright, is readily apprehended through the continuous postural adjustments made to this force. Second, the visual environment has the character of a framework, whose main outlines represent the true vertical and horizontal; this also provides a ready basis for establishing the upright. The cooperation between these two sets of factors is ordinarily very intimate, resulting in a unified impression of the upright; and furthermore, since the visual and gravitational uprights coincide in direction, the outcome is the same whichever determinant is used as the main basis of perception. It is clear that in order to determine whether a given judgment of the upright is made with reference to the visual framework or with reference to body position, or by a compromise between them, one must in some way separate these two standards.

This was done in one series of studies (1, 2, 5, 11) by tilting the visual field, so that the visual standard was altered, while the gravitational standard remained unchanged. In another series of studies (7, 9) the separation was accomplished in the converse way - the room in which the subject was seated was rotated about a circular track, so that the effective force acting on his body was changed, but the visual field represented by the room remained upright. In still another study (10) the visual field was eliminated entirely by working in a completely darkened room, so that the person had to rely on postural experiences alone in determining the upright. Throughout these experiments exact quantitative determinations were made of the subject's location of the upright by having him adjust his own body, or the whole surrounding field, or a rod within the field to a position in which he perceived it as upright.

Together, the results of these studies indicated that under everyday circumstances, when a "strong" visual field is present, the field provides the main basis for perception of the upright, and that postural experiences, although they are used to a great extent, serve in a secondary way. Here, as in other kinds of perceptual processes, constancy seems to be primarily a function of the presence of a stable, well-articulated visual field.

*ONR Project NR 143-200, Contract N7onr-323 T.O. 1

In the course of these studies, a striking result emerged, more or less as a by-product of our main interest in the sensory experiences contributing to perception of the upright. In all the experimental situations described, fairly large groups of subjects were employed; in each it was found that the individual results, upon which means were based, covered a very wide range. Because of this great variation among individuals, no statement about the nature of perception under a given condition, derived from average values for the group, held true for all individuals in the group. Moreover, in a variety of ways, the evidence indicated that a person tended to exhibit a characteristic kind of perception, which was not subject to change, and which seemed to be associated with other more general aspects of his psychological make-up. This suggested that for a full understanding of the process of orientation one must go beyond group results to consider the basis of individual variations in perception.

These findings, which represented the state of our knowledge when the present studies were undertaken, pointed out two important directions for further investigation. The first concerned the problem of extent of self-consistency in perception; the second concerned the problem of the origin of the person's particular kind of perception, and the basis of differences in perception among people. It is with these two problems that our ONR project has been concerned since its inception in 1947.

Before considering the results of the studies carried out to investigate these problems, it seems desirable to describe more fully the nature of individual differences in space orientation, and the tests used in evaluating the person's mode of orientation.

THE NATURE AND MEASUREMENT OF INDIVIDUAL DIFFERENCES IN MODE OF ORIENTATION

The Tests of Space Orientation

To investigate individual differences in manner of establishing the upright, three standardized test situations were developed (4). Together these tests evaluate the way in which the person determines the position of his body in relation to the upright, the direction of the field as a whole, and the direction of an item within a field. In each test the upright indicated by the visual field is in a different position than the upright indicated by postural impressions; and with these conflicting standards available to him, the subject is required to locate the upright by adjusting an item (his body, the field, or a rod) to where he perceives it as straight. This procedure makes it possible to express the subject's perception in exact quantitative terms.

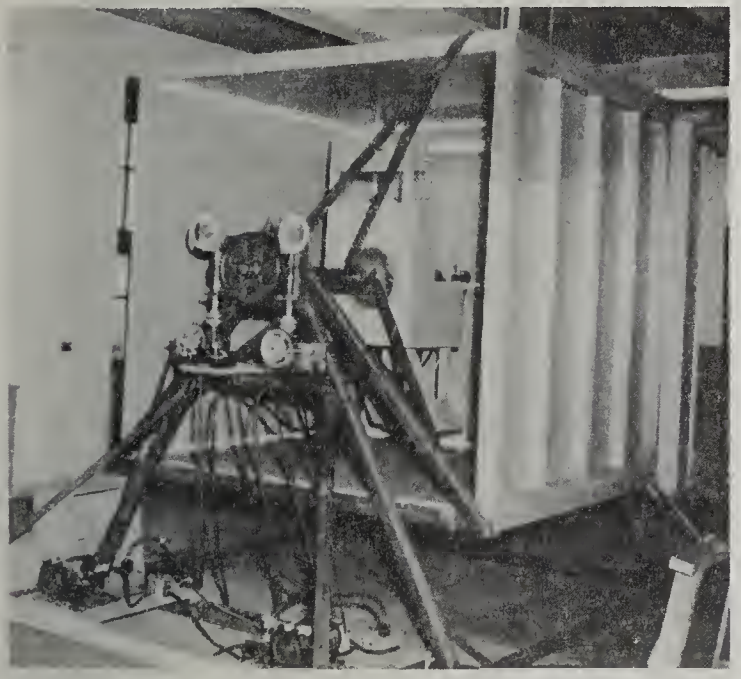

Figure 1 - The tilting-room-tilting-chair test apparatus

The Tilting-Room-Tilting-Chair Test. This test evaluates the individual's perception of the position of his body, and of the whole surrounding field, in relation to the upright. The apparatus used consists of a small room within which is a chair (Figure 1), both of which may be tilted to left or right, by any amount, either by the experimenter or by the subject seated in the chair. Since room and chair are provided with independent driving mechanisms, they may be tilted alone or together, to the same side or opposite sides, at the same speed or different speeds. The subject, seated in the chair, cannot see outside the room in which he is contained, so that his judgments of the upright must be based on whatever information he can obtain from his own body and from the visual field of the experimental room. The test procedure consists of tilting the room and chair to set positions, and then requiring the subject to adjust one or the other to the upright—the room on some trials, his chair on other trails. The positions to which room and chair are brought may be measured to the nearest degree, so that the results are represented in quantitative terms.

The Rod-and-Frame Test. This test evaluates the individual's perception of the position of an item in a field. The apparatus used (Figure 2) consists of a luminous square frame, pivoted at its

center so that it may be tilted to left and right, and a luminous rod, pivoted at the same center, but moving independently of the frame. Since the test is conducted in a completely darkened room, all the subject can see are the frame and the rod. These are presented in tilted positions, and the subject is required to adjust the rod to the true upright while the frame remains in its initially tilted position. As a further variable, the subject's body is upright during some trials, tilted during others. It is, of course, much more difficult to make use of one's body in judging the position of a distant line when the body is tilted than when it is erect. In this test, therefore, it is possible to determine the extent to which the subject is able to make use of postural experiences in overcoming the influence of the frame, both at times when it is easy to use these experiences and at times when it is difficult. In the standard test, frame and rod are initially tilted on each trial; and on some trials the subject's body is tilted as well. The task is to adjust the rod to the true upright.

Figure 2 - The rod-and-frame test apparatus

The Rotating-Room Test. This test evaluates the subject's perception of the position of his body and of his surroundings when the direction of the force acting on his body has been changed. In the two previous tests the procedure followed was that of tilting the field and tilting the body. Whereas tilting the field does fundamentally change the direction of the visual upright, tilting the body does not at all change the direction of the gravitational upright. Though more difficult than with body upright, it is still possible when the body is tilted to detect the direction of gravity through the bodily sensations arising from postural adjustments to this pull. The rotating-room test, however, by actually altering the direction of the force acting on the body, changes the postural factors in a more fundamental way. To alter the force on the body, an outward-acting centrifugal force produced by rotating the subject is added to the downward pull of gravity, yielding a resultant with a direction intermediate between the two forces. The apparatus employed (Figure 3) consists of a small, fully-enclosed room, mounted on a carriage that is driven about a circular track. This room may be tilted from side to side, and contains a chair that may also be tilted to one side or the other. The rotation of the whole unit and the tilting of room and chair are controlled by the experimenter from the outer laboratory. The standard test consists of two parts. In both parts, room and chair remain in their initial objectively upright positions on each trial; but in one part the subject's task is to make the room straight if it appears tilted to him, and in the other it is to make his chair straight if he perceives himself as tilted.

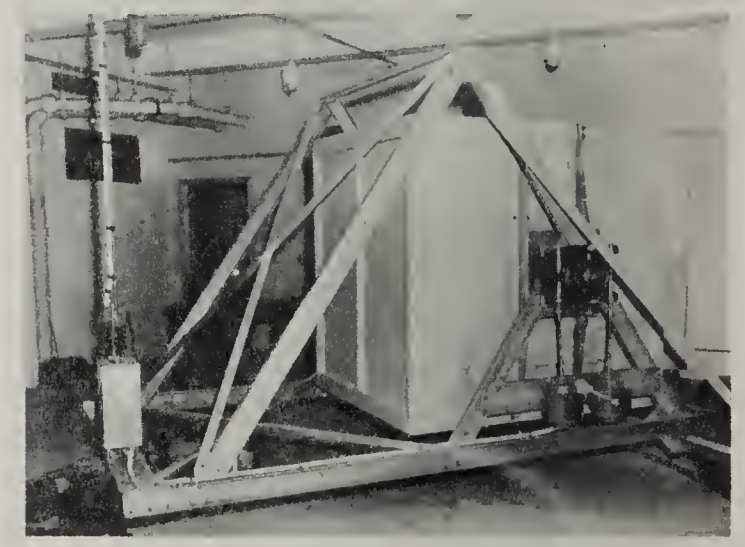

Figure 3 - The rotating-room test apparatus

The Nature of Individual Differences in Mode of Orientation

Studies with the situations used in these three tests have established general principles governing orientation toward the upright. The following discussion will be limited, however, to those findings that are related to the problem of individual differences in perception.

Though presenting a variety of conditions, the three test situations have an important feature in common: they all involve a conflict between the main (visual and postural) determinants of the perceived upright. Therefore each presents the problem of integrating these conflicting sensory experiences and arriving at a unified perceptual impression. The results clearly show that in all the test situations subjects differed markedly in how they resolved the conflict and, consequently, in how they perceived the situation. Specifically, they differed with regard to the relative emphasis assigned to visual

impressions and to bodily experiences in the final integration. Whatever the outcome, a given way of perceiving the situation represented in almost all cases an automatic and spontaneous experience for the person. Thus, in the tilting-room-tilting-chair test, with the structure of the situation identical for all subjects, the room (tilted at 56°) immediately looked straight to some, looked mildly tilted to others, and looked very much tilted to still others. The same kinds of differences were found in the way the subjects perceived their own body position. These findings indicate that even a fairly well-structured situation will not be perceived in the same way by everyone. The discovery of such differences; of course, is dependent on the use of appropriate experimental procedures.

The nature and extent of the observed differences in perception may be illustrated with some specific results for each of the three tests. First to be considered is the tilting-room-tilting-chair test, and in particular that part of the test in which the subject was required to adjust the room to the upright. Most often in this situation subjects tended to "go along with the field," so that the perceived upright was shifted toward the vertical of the tilted room. Some subjects simply identified the true upright with the vertical of the room, perceiving the room at the outset as fully erect at its initial 56° tilt. Others located it somewhere between the vertical of the room and the vertical indicated by experiences of body position, and moved the room from its initial tilt to some position closer to the true vertical. Still others, few in number, were successful in bringing the room to the true upright, indicating that they judged the upright independently of the field and in accordance with the position of the body. In one series of trials, for example, where room and body were both initially tilted to opposite sides and the task was to straighten the room from its 56° tilt, the average scores (representing the objective tilt of the room when it was judged to be upright) were 22.9° for men and 28.1° for women. Examples of extreme performance were found at both ends of the range. One subject, a man, succeeded in bringing the room to within an average of 2.5° of the upright in the four trials of this series; another subject, a woman, perceived the room as upright at its initial 56° tilt on all four trials.

Equally striking differences were obtained in that part of the test where the subject's perception of the position of his own body was evaluated. When required to straighten the body, with the room tilted, most subjects moved it in the direction of the tilt of the room, indicating that they based their judgments not only on how the body felt, but also on how it looked—i.e., whether or not it was aligned with the surrounding field. (The average amount of tilt of the subject's body when it was judged to be upright was 9.0° for men and 11.0° for women for trials where room and body were initially tilted to the same side.) Most subjects moved the body to some position intermediate between the vertical of the tilted room and true upright. Others succeeded in bringing it to the true upright, regardless of the position of the room, basing their judgments entirely on bodily sensations. Still others, at the opposite extreme, moved the body into alignment with the tilted room, indicating that the visual basis of judgment alone was being used, to the neglect of bodily sensations. This visual mode of orientation is dramatically illustrated in the following result. In one series of trials, where room and chair were tilted to the same side, some subjects reported the body as tilted to the side opposite to its actual tilt. With the chair at 22° left and the room at 35° left, for example, such individuals judged themselves to be tilted right and requested that they be moved to the left to become straight. When the chair was brought to a position of near-alignment with the tilted field, they judged themselves to be upright. This obviously illustrates the use of a purely visual basis for perception of position. Experiments have established that contradictory postural sensations are actually suppressed under the influence of these strong visual impressions, even when large objective tilts of the body are involved.

Turning to the results for the rod-and-frame test, one again finds a very wide range of performances under all the conditions used. In this situation, when an objectively upright rod is surrounded by a tilted frame in the absence of any other visual field, the rod appears, to almost everyone, to be tilted in the opposite direction to the frame. Accordingly, when asked to adjust the rod to the upright, most subjects displaced it from the upright in the direction of the tilt of the frame. In the two series where the body was tilted (with the frame tilted to the same side as the body in one series and to the opposite side in the other), the mean amounts by which the rod was displaced were 16.7° and 18.3° for women, and 12.5° and 14.5° for men. In another series, where the body was erect and therefore more useful in estimating the upright, the mean amount of displacement of the rod was 12.1° for women and 7.4° for men. In general, then, the tilted frame exerted a marked influence on the perceived position of the rod, especially when the body was tilted. When individual performances are considered, however, it is found that people differed very markedly in the extent to which they were affected by the frame. Some subjects were able to escape the influence of the frame, both with body erect and with body tilted, and succeeded in bringing the rod to within a few degrees of the true upright. The ability to perceive the rod independently of the field, or to deal with the presented visual situation analytically, undoubtedly

reflects the effective use of body experiences as a basis for perception. Other subjects—and these constituted the largest group—"went along with" the frame to various extents, bringing the rod to a position that represented some degree of compromise between the vertical of the tilted field and the vertical indicated by the body. For a third group, perception of the rod continued to be based almost exclusively on its relation to the frame. In such cases the tilted frame itself was usually perceived as fully upright, so that straightening the rod became a simple matter of aligning it with the frame. Among subjects whose perception depended upon the frame in this extreme fashion, a very striking phenomenon was observed. At times, in the absence of any actual movement, the subject would suddenly experience a perceptual shift in the axes of the frame, so that its topmost side would be perceived as its left side, for example—that is, parallel to the left wall of the unseen outer room. When perception of the frame showed this kind of lability, alignment of the rod with the shifted axes, of course, led to exceedingly large errors in the estimation of the upright. Surprisingly, these shifts occurred even when the subject's body was upright. When this happened, the subject might report that the rod was upright (and therefore presumably aligned with his erect body) when it formed a 62° angle with his body.

The range of quantitative results in adjustment of the rod to which these differing modes of perception led may be illustrated with the data for the series of trials where the body was erect. One subject, a male, succeeded in adjusting the rod to within an average of less than 1° of the upright in the eight trials of the series. At the opposite extreme another subject, a female, made errors averaging 40.1° in these eight trials (even though she was sitting erect and therefore had the opportunity of simply aligning the rod with her body). On some of the trials this subject experienced perceptual shifts of the frame.

Considering finally the results for the rotating-room test, great variability among subjects is found, again depending on differences in manner of integrating visual and postural impressions. With the force on the body forming a 39.9° angle with the true upright, most subjects tilted both room and body in a direction opposite to the direction of this force, when required to make them upright. This alteration of the postural determinant of position thus led to a shift in the perceived positions of both body and field, though the shift did not correspond in magnitude to the change in the force.

Examination of individual performances shows that people were affected quite differently in their perception by the change in the force acting on their bodies. In almost all cases subjects felt tilted, to various degrees, while seated in the upright chair during rotation. Many also perceived the upright room as tilted, again to various degrees. When asked to adjust themselves to the upright, some subjects, at one extreme of the performance range, moved themselves to positions approximately at right angles to the force and thus compensated for it in full. These subjects moved the room to an equally marked extent; for them the force experienced by their bodies was the main determinant in perceiving body and field position. At the opposite extreme were subjects for whom the room continued to appear fully upright throughout rotation and who therefore did not need to move it at all. In this area of the distribution there were even instances in which its alignment with the field caused the body itself to be perceived as fully upright throughout rotation. This manner of perception reflected a complete disregard of the intense lateral tug on the body. It is clear that under the same field conditions and with a force of the same magnitude and direction acting on their bodies, people differ markedly in their perception.

CONSISTENCY, STABILITY AND GENERALITY OF THE INDIVIDUAL'S MODE OF PERCEPTION

Now that we have considered the nature of the perception found in each part of the three orientation tests we may proceed to examine the results of studies carried out to determine whether a given way of perceiving, as revealed in one of these orientation tests, represents a pervasive characteristic of the individual.

Consistency of Perception

Having found differences in perception in each part of the three orientation tests, the next question for consideration related to the consistency of a given person's mode of perception in different parts of a given test and in the different tests. To answer this question, the three tests were given to a large group of subjects, and the correlations were computed among the parts of each test and among the three tests (Table 1). In view of the existence of important sex differences in performance in these tests (to be considered later), results for men and women have been treated separately. For both men and

women, the values are sufficiently high to indicate that the manner of a person's orientation toward the upright is fairly consistent, whether the specific task involves perception of the position of a part of a field, of the field as a whole, or of one's own body. More specifically, a tendency to rely mainly on the visual framework or mainly on bodily experiences represents a fairly general characteristic of the individual's orientation.

TABLE 1

Intercorrelations among Basic Parts of Each Orientation Test and among the Three Tests

Test Situation	Men (N=46)	Women (N=45)
1. Tilting-room-tilting-chair test: Room-adj. series vs. chair-adj. series	0.60*	0.42*
2. Rod-and-frame test: Body-tilted series vs. body-erect series	0.70*	0.66*
3. Rotating-room test: Room-adj. series vs. chair-adj. series	0.58*	0.62*
4. Tilting-room-tilting-chair test vs. rod-and-frame test	0.64*	0.52*
5. Tilting-room-tilting-chair test vs. rotating-room test†	-0.51*	-0.63*
6. Rod-and-frame test vs. rotating-room test†	-0.25	-0.18

* Significant at or below the 1-percent level of confidence
† The negative correlations between the rotating-room test and the other two tests occur because, in the former, "going along with" the visual field results in little or no displacement of body and room from the upright, whereas in the latter it results in larger displacements of body, room, and rod.

Stability of Perception

The next question to be considered is whether a given mode of perception is a transient feature of the person or whether it tends to characterize him over an extended period of time. An answer was provided by a study in which a group of subjects was retested in the tilting-room-tilting-chair situation and in the rod-and-frame situation after a period of more than a year. The test-retest correlations for the two situations, respectively, were 0.85 and 0.88 for men and 0.86 and 0.87 for women. These values are very high, especially for the types of tests used, and indicate marked stability in the individual's perception, as far as orientation toward the upright is concerned.

Relation between Performances in Orientation and Nonorientation Perceptual Situations

The correlations presented in Table 1 show a fairly high degree of consistency in the individual's perception in situations involving orientation toward the upright. Do the perceptual features shown in these orientation situations tend to characterize the individual's perception generally, or do they appear only in this particular type of situation? To answer this question, a study was made of consistency of perception under widely varied conditions. Employed in the study were the three orientation tests described above and in addition a number of nonorientation perceptual tests.

Nonorientation Perceptual Tests

1. Embedded-Figures Test (8). The subject was required to locate as quickly as possible a previously shown simple figure "hidden" in a complex visual design. Here, as in some of the orientation tests, the subject's ability to deal with an item independently of the surrounding field was evaluated; but the body was not involved nor was the process of space orientation.

2. Body-Steadiness Test (2). Using an ataxiameter type of device, the amount of body sway exhibited by the subject when surrounded with a stable and an unstable visual field was evaluated. The interest here was in determining the extent to which the subject's ability to maintain a given position of the body was affected by events in the outer field. In this respect this test resembled some of the orientation tests, although perception of the upright was not at issue here.

3. Body-Balance Test (3). A stabilometer type of device was used to evaluate the subject's ability to balance a tiltable platform on which he was standing, when the surrounding visual field was stable and unstable. This test is similar to the body-steadiness test, except that the postural task here is a considerably more difficult one.

4. Auditory-Visual Conflict Test (13). The subject was required to locate a sound source which provided conflicting visual and auditory cues. Reliance on one type of cue resulted in a different location of the sound source than reliance on the other type of cue. Where our orientation tests involved a conflict between visual and postural experiences, this test involved a conflict between visual and auditory experiences.

5. Two-Hand Coordinator Test. This was one of the standard pursuitmeter tests which are now in common use. The subject was required to keep a small knob in contact with a moving target which followed an erratic course. The path of the knob was determined by turning two handles: one with the left hand, which accomplished movement toward and away from the subject, and the other with the right hand, which accomplished left and right movement. Good performance in this test depended primarily upon effective visuo-motor integration.

6. Patch-Match Brightness-Constancy Test. The subject was presented with a patch of gray paper, and he was required to choose a patch which matched it from a series of patches ranging in brightness from white to black. The test patch was in shadow while the series from which the choice had to be made was illuminated. Effective matching depended upon the subject's ability to disregard the effect of the illumination in judging the brightness of the test patch. This test thus resembled the orientation tests and the embedded-figures test in featuring the subject's proficiency in dealing with an item independently of its surroundings. As in the embedded-figures test, the body was not involved here nor was the process of space orientation.

Test Correlations. The correlations between the scores for the nonorientation tests and the combined scores for the three orientation tests (the orientation index score) (Table 2) are, with only one exception, positive. The correlations between the orientation tests and the embedded-figures test are high and significant. Those between the orientation tests and the body-balance test, the two-hand coordinator test, and the patch-match test are lower, but tend toward significance. Finally, there seems to be no real relationship between the orientation tests and body-steadiness and auditory-visual conflict tests. This undoubtedly reflects the operation of special factors unique to each of the latter tests, which overwhelm the factors especially featured in the orientation tests.

It is striking to find that performance in the orientation tests bears a relation to performance in a test which is as different from them as the embedded-figures test. In particular, it is indicated that difficulty in locating the simple figure in the latter test (that is to say, difficulty in escaping the influence of the complex field) tends to be associated with dependence on the surrounding framework in perception of the upright in the three orientation tests. The significance of this finding is most impressively illustrated in the relation found between chair-adjustment results in the tilting-room-tilting-chair test and results for the embedded-figures test. The correlations between these two test situations were 0.54 for men and 0.58 for women. These values indicate that people who found it difficult to extract the simple figure from its context also found it difficult to "separate" their own bodies from the tilted field, and to determine their position independently of their relation to the field. It is indeed a very dramatic finding that a simple, neutral visual design should be perceived by a person on the same basis as the

position of his own body. Similarity of perception under such very different circumstances provides very effective proof of the presence of consistent and pervasive characteristics in the individual's perception.

TABLE 2

Correlations between Orientation Tests and Nonorientation Tests

Nonorientation Tests	Orientation Index Score	
	Men	Women
Embedded-figures test	0.66**	0.46**
Body-steadiness test	0.16	-0.04
Body-balance test	0.26	0.30*
Auditory-visual conflict test	0.17	0.08
Two-hand coordinator test	0.57**	0.34*
Patch-match brightness-constancy test	0.14	0.41**

* Significant at or below the 5-percent level of confidence
** Significant at or below the 1-percent level of confidence

In general, these results on performance in a varied battery of perceptual tests indicate that, in addition to being different from each other in their perception, people also tend to be self-consistent in mode of perception.

Sex Differences in Perception

The results for the perceptual tests (both orientation and nonorientation) considered in the previous section showed striking differences in perception between men and women (6). Moreover, the differences were always in the same direction—women "going along with" the visual field more than men and responding less to bodily experiences. Thus, in the tilting-room-tilting-chair test, women in general accepted the room as straight at more tilted positions than did men, and in attempting to make their bodies upright tilted them farther in the direction of the visual field. In the rod-and-frame test, they tended to align the rod with the tilted frame more than did men, and this occurred both with body erect and with body tilted. Finally, in the rotating-room test, women were much less affected than men by the displacement of the force acting upon them, and they accordingly tilted both room and body less in compensating for this force. The differences in scores between men and women were large and significant for almost all parts of the three orientation tests.

The same kind of sex difference was observed in the embedded-figures test, where women did more poorly than men, indicating that their perception of the simple figure was more strongly affected by the structure of the surrounding field. In the body-steadiness and body-balance tests it was found that instability of the surrounding field caused much more disturbance in women than in men. Similarly, in the audio-visual conflict test, women as compared with men tended to locate the sound more in accordance with where they saw it originate than where they heard it, under conditions of conflict between visual and auditory cues. Also, women were a good deal poorer than men in the two-hand coordinator test.

These differences between men and women in susceptibility to influence by the structure of their surroundings are thus pervasive and represent a difference between the sexes of very great importance. The finding of perceptual differences associated with as broad and fundamental a differentiation of people as sex supports the conclusion that a given mode of perception represents a deep-seated characteristic of the individual.

PERSONALITY DETERMINANTS OF PERCEPTION

It had been established at this point in our investigation that people differ very markedly from one another in manner of orienting themselves in space. In a variety of ways our evidence suggested that the basis of these differences could not profitably be sought at a sensory level. For one thing, the range of individual differences in perception seemed to exceed the possible range of variation in acuity of the senses involved; nor did there seem to be any relation between acuity of a given sense (e.g., vision) and the emphasis assigned by the person to experiences from that sense in his orientation (e.g., his dependence on visual impressions). Moreover, orientation requires the use of a number of different senses, and, as in any perceptual process calling for the cooperation of several senses, the manner of integration of the different sensory experiences is more important in determining the final perception than are the specific operations of any of the senses involved. To the extent that integration is important, a higher-level determination of the final form of the perception is indicated. All this suggested that, even if specific sensory factors contribute to individual variations in space perception, they are not the main determinants of these variations.

At the same time, certain observations indicated that the manner in which the person orients himself is very likely related to his more general psychological characteristics. The finding, for example, that men and women tend to be different in their space orientation shows that manner of orientation is associated with such broad over-all psychological features as maleness and femaleness. Furthermore, as we have already noted, since our orientation tests confront the person with a conflict (between a standard based on impulses from his body and a standard offered by the environment) which is of a commonplace kind and one to which people work out characteristic ways of adjusting, an organismic conception of psychological functioning would lead us to expect that the way in which a person handled conflict in our orientation tests would represent his general way of coping with this kind of conflict. Finally, preliminary experiments carried out in preparation for the present study offered suggestive evidence that certain personality patterns occurred more often among people who showed given kinds of orientation.

These considerations led us to seek the basis of individual differences in space orientation and in differences in personality structure. This study of the relation between perception and personality was carried out mainly with a normal population, consisting of Brooklyn College students. Each of 103 subjects was given the battery of orientation and nonorientation tests described previously. In addition, his personality was studied by means of the following battery of clinical tests: the Rorschach Test, the Thematic Apperception Test, a sentence-completion test, an interview, a personality questionnaire, a word-association test, an autobiography, and the Machover Figure-Drawing Test. These tests were administered and interpreted by three different investigators. One handled the autobiography, personality questionnaire, sentence-completion test, and interview; another dealt with the Figure-Drawing Test; and a third with the Rorschach Test, Thematic Apperception Test, and word-association test. Results for each personality test were evaluated separately, except for the autobiography and personality questionnaire, which were treated as part of the interview.

The results of each personality test were quantified, so that they could be related through correlational procedures to the scores obtained from the perceptual tests. In arriving at a scoring procedure for a given personality test, the test features selected were those which referred to basic dimensions of personality relevant to the perceptual characteristics under study.

Correlations between the scores for each personality test and the orientation index score indicate the existence of an impressive relationship between perception and personality (Table 3). In view of the features involved in the perceptual and personality tests used, it may be stated that people who generally depend on visual experiences in their perception of the upright are likely to be characterized in their personalities by lack of self-awareness, repressed hostility, passivity and anxiety (as revealed in the interview); by lack of a well-developed self, and inability to organize coping responses (as revealed by the Rorschach); and by lack of body confidence, absence of a struggle for identity, and immature handling of drives (as revealed by the Figure-Drawing Test). Conversely, people who rely mainly on postural experiences tend to show such personality characteristics as self-assuredness, activity, self-awareness, body-confidence, etc.

The main aspect of personality expressed in our perceptual tests is related to the organization of the self. Personalities characterized by considerable repression of impulse, by passive attitudes, and by a mode of handling drives which results in a weakening of the sense of self, are visually oriented.

TABLE 3

Correlations between Perceptual Variables and Personality Variables

Personality Tests	Orientation Index Score	
	Men	Women
The Interview	0.60**	0.64**
Rorschach Test	0.69**	0.57**
Figure-Drawing Test	0.73**	0.69**
Thematic Apperception Test	0.47**	0.53**
Word-Association Test	0.32*	0.07
Sentence-Completion Test	0.27	0.00

* Significant at or below the 5-percent level of confidence
** Significant at or below the 1-percent level of confidence

Personalities in which the self is considerably developed (including pathological developments of the self, as in paranoia) tend to be posturally oriented. It should be noted in this connection that neither extreme reliance on postural experiences nor extreme reliance on visual experiences is related to personality adjustment. In fact, those who compromise between these two types of experience, so that they are found in the middle range of our distribution, tend to be better adjusted than those who rely mainly on the one experience or the other.

This study thus showed an intimate relationship between mode of perception and the basic personality structure of the individual.

Our findings for the Brooklyn College group suggested the desirability of obtaining more extreme cases for some of our diagnostic categories than had been found in the college population. They also indicated the need for investigation of certain personality categories that occurred rarely, if at all, in the college group. In particular, it seemed desirable to examine the nature of perception in extremely withdrawn, isolated people, such as schizophrenics; in "collapsed" people, who are capable of very little "struggle for self"; in psychopaths; and in paranoids. There was a second purpose, of a methodological nature, for studying an abnormal population. Our work with the Brooklyn College group, which was completed before the study of hospital cases began, had established that certain personality variables (or "signs") were associated with particular kinds of perception. One way of establishing the validity of these signs was to determine whether they bear the same relation to perception in a new and independent group as they had in the original group for which they were developed. An abnormal group served to provide an independent population for checking our personality signs.

These considerations led us to carry out a supplementary study on 78 patients at the Psychiatric Division of the Kings County Hospital. The results obtained support in general the picture of perception-personality relationships established for the normal population.

THE DEVELOPMENT OF PERCEPTION

The experiments on personality determinants of perception outlined in the previous section represented one approach to the problem of the origin of individual differences in perception. Another approach to the same problem was to study perception at different stages of psychological development. This area of study was intended to provide information about: (a) the range of individual differences in perception at different ages, (b) personality correlates of the patterns of perception observed at different ages, (c) the nature and extent of changes in perception during development, and (d) the extent of sex differences in perception below the adult level.

Test Procedure

An abbreviated series of our perceptual tests was given to groups of approximately 30 boys and 30 girls at five different age levels—8, 10, 13, 15, and 17 years. Perceptual data for about 300 children were thus gathered. Eight years was chosen as the earliest practical age to work with, for it had proved difficult to apply our rather complex perceptual techniques with younger children. Each child was given the following perceptual tests: tilting-room-tilting-chair, rod-and-frame, and embedded-figures test. The last of these was omitted with the 8-year olds, because it proved too difficult for them. Each child's physical maturity was evaluated, in terms of skeletal age, by an analysis of X-rays of wrist-bone development. A record of their I.Q.'s, as established by standard intelligence tests, was furnished by the schools in which they were enrolled.

After the perceptual results had been obtained, smaller representative groups of each sex at the 8-, 10-, and 13-year levels were chosen for intensive personality study. In each instance, the smaller group provided a distribution of perceptual scores similar to that of the larger group from which it had been selected. The personality study consisted of an individually administered Rorschach Test, the Thematic Apperception Test, the Machover Figure-Drawing Test, and a Miniature-Toys Play Situation.

Main Results

(a) The developmental picture for tasks involving perception of the field as a whole was quite different from that for tasks involving perception of an item within a field. For the former type of task, the developmental curve showed essentially no change between 8 and 17 years, although numerous up-and-down fluctuations occurred. For the latter type of task, it was found that at 8 and 10, there was marked dependence on the surrounding visual field. Between 10 and 13 a dramatic change occurred in the direction of striking independence of the field; and this independence of the field also tended to be characteristic of 15- and 17-year olds. Beyond that age, a reversal occurred, in the sense of a tendency to return to greater reliance on the field. This happened to a much greater extent with females than with males.

(b) At all ages, females in their perception showed greater dependence on the visual field than males; but it was not until the 18-20 year age range that this difference became large enough to be statistically significant. Females also tended to be more variable than males.

(c) The greatest self-consistency in perception under different test conditions was found in the 18-20 year age period.

(d) In almost all of our test situations the wide range of performances found at the adult level was also found among 8-year olds and in each of the older groups. This suggested that the markedly different modes of perception with which we have been concerned are established quite early in life.

(e) Methods of analysis of the perception-personality relationships in children followed the pattern established for the adult data except for changes dictated by the personality test materials themselves. In general, the perception-personality relationships found in children were similar to those established for adults.

The results of these studies with children showed striking developmental changes in perception. They also indicated that differences in perception among people appear at an early age, with differentiation occurring in relation to specific aspects of personality organization.

CONCLUSIONS

Traditionally, research in perception has been carried out under the influence of one or the other of two main theoretical approaches. In one approach, an explanation of perceptual experiences has been sought in the structure of the prevailing field. In the other, emphasis has been placed on the physical properties of the stimulus giving rise to the perceptual experience, and on the specific operations of the sense organs and associated neural structures mediating the stimulus. There is no doubt that basic determinants of perception are to be found in structural characteristics of the field and in sensory and neural mechanisms. Studies such as those reported here have shown, however, that these factors do

not provide a fully adequate account of the nature of perception. It is now clear that perception is determined in important ways by the motivation of the perceiver. Only if general psychological factors within individuals are considered along with field factors and sensory factors will it be possible to arrive at fully comprehensive laws of perception.

Our findings concerning the determinants of space orientation in man and concerning the basis of individual differences in mode of orientation have many practical implications. While their relevance to the flying situation (particularly to problems of selection and training) is particularly apparent, they are probably applicable to many situations in which perception is involved, and in which the suitability of different individuals for a given perceptual task must be determined. The solution of these and other practical problems in perception will be hastened to the extent that our understanding of perception is enhanced through basic studies of the kind reported here.

* * *

REFERENCES

1. Asch, S. E., and Witkin, H. A., "Studies in Space Orientation: I. Perception of the Upright with Displaced Visual Fields," J. Exp. Psychol. 38: 325-337, 1948

2. Asch, S. E., and Witkin, H. A., "Studies in Space Orientation: II. Perception of the Upright with Displaced Visual Fields and with Body Tilted," J. Exp. Psychol. 38: 455-477, 1948

3. Wapner, S., and Witkin, H. A., "The Role of Visual Factors in the Maintenance of Body-Balance," Amer. J. Psychol. 63: 385-408, 1950

4. Witkin, H. A., "The Effect of Training and of Structural Aids on Performance in Three Tests of Space Orientation," Civil Aeronautics Administration, Division of Research, Report No. 80, 85 pp.

5. Witkin, H. A., "Perception of Body Position and of the Position of the Visual Field," Psychol. Monog. 63: 1-46 (No. 302) 1949

6. Witkin, H. A., "Sex Differences in Perception," Trans. N.Y. Acad. Sci. 12: 22-26, 1949

7. Witkin, H. A., "Perception of the Upright when the Direction of the Force Acting on the Body is Changed," J. Exp. Psychol. 40: 93-106, 1950

8. Witkin, H. A., "Individual Differences in Ease of Perception of Embedded Figures," J. Personality, 19, 1950

9. Witkin, H. A., "Further Experiments on Perception of the Upright when the Direction of the Force Acting on the Body is Changed" (in preparation)

10. Witkin, H. A., and Asch, S. E., "Studies in Space Orientation: III. Perception of the Upright in the Absence of a Visual Field," J. Exp. Psychol. 38: 603-614, 1948

11. Witkin, H. A., and Asch, S. E., "Studies in Space Orientation: IV. Further Experiments on Perception of the Upright with Displaced Visual Fields," J. Exp. Psychol. 38: 762-782, 1948

12. Witkin, H. A., and Wapner, S., "Visual Factors in the Maintenance of Upright Posture," Amer. J. Psychol. 63: 31-50, 1950

13. Witkin, H. A., Wapner, S., and Leventhal, T., "Localization of a Sound with Conflicting Visual and Auditory Cues" (in preparation)

FACTORS INFLUENCING THE PERCEPTION OF THE VERTICAL*

Cecil W. Mann
Tulane University
New Orleans, Louisiana

INTRODUCTION

Man is normally a daylight-living animal, and most of his coordinated movements take place in a two-dimensional plane. Under these conditions, he normally makes fairly accurate judgments of the verticals and horizontals of the visual field and, even in the absence of visual stimulation, he can maintain postural balance. When he takes to three-dimensional space, as in flight, his judgments of visual field and body position are complicated by the forces necessary to keep the plane in flight. Conditions of poor visibility during flight may lead to confused judgments resulting from his inability to resolve the conflict between the visual and gravitational forces.

Cecil W. Mann received his B.A. and M.A. from the University of Sydney, Australia, and the Ed. D. degree from Stanford University. After being Director of the Bureau of Testing in Louisiana from 1942 to 1945, he became Professor of Psychology at Tulane University where he is now Chairman of the Psychology Department.

Wertheimer and Koffka have suggested that visual space is highly labile, determined by the visual organization. In support of this position they point to the disturbances which occur in the perception of both visual and postural verticals when the main lines of visual space are made to deviate from the gravitational vertical. It should be noted that, in the absence of visual cues, the individual is able to make quite accurate judgments of the postural vertical. Moreover, when the direction of the gravitational force and the visual framework are altered - as in a centrifuge or in a banking plane - the perceived vertical deviates in the direction of the resultant force. Gibson and Mowrer stress the importance of gravitational forces in the process of orientation and propose the hypothesis that "both the visual and postural vertical are determined by visual and gravitational forces acting jointly, with orientation to gravity, however, as the more decisive factor in cases of real conflict between the two types of sensory data, and the primary factor genetically."

The development of civil and military aviation has led to many investigations of the influence of forces during flight upon perception. Under conditions of unusual plane attitude, and during poor visibility, pilots have reported various degrees of disorientation. Somesthetic and gravitational cues may become so strong that the pilot finds it difficult to trust his instruments. An examination of some of the basic experimental findings in space perception should throw light upon the factors which produce disorientation during flight.

Under Normal Conditions

The intact organism readily maintains equilibrium and even in the absence of visual cues makes accurate judgments of the postural vertical and horizontal. In order to investigate the problems of lateral tilt, a tilting chair was constructed at Tulane. The chair was housed in a dark room. Controls enabled the chair to be controlled either by the subject or the experimenter; recording devices were provided by pairs of selsyns which enabled judgments to be recorded to an accuracy of 0.5°.

The mean constant error made by subjects returning themselves to the gravitational vertical from positions of lateral tilt of from 5° to 90° was 0.8°; the mean variable error was 1.9°. The

*ONR Project NR 143-455, Contract N7onr 434 T.O. 1

subjects commented on the fact that while they were certain of the feeling of tilt at positions deviating markedly from the true vertical, say 30° or 45°, there was much uncertainty as they approached the vertical. This uncertainty is reflected in the relative values of the mean constant and variable errors. It was found that the judgments of all subjects tended to be distributed normally with a slight skewness in the direction of underestimating the vertical. It is proposed to define an "arc of uncertainty" (U°), arbitrarily the middle 75 percent of the subjects' judgments. In this series the value of the arc of uncertainty was found to be 4.4°.

Comparisons were made of judgments of the postural vertical following tilt in lateral, medial, and oblique planes. A link trainer modified by the removal of the turning motor was used in this study. It was found the subjects were most sensitive to tilt and showed greatest accuracy of judgment when tilted in the lateral plane.

Analysis of results of recent studies in tilt appear to indicate that under certain conditions there is improvement of performance with practice.

Under Modified Somesthetic Cues

Under favorable circumstances, the intact organism will utilize all appropriate perceptual modalities in determining and responding to position in space. It would be expected that modification of perceptual modalities will influence the judgment of postural vertical. One method of modification would be by varying the cutaneous and kinesthetic cues. This was done by padding the tilting chair with several layers of foam rubber to modify the pressures on the lower trunk during tilting. Under these conditions, there was no significant difference in mean constant errors, but a substantial increase in variable error. Under these conditions the subject is apparently not able to make his judgments with as much certainty as he is under normal conditions.

Adaptation Effects

The continuous application of a stimulus above threshold tends to produce sensory adaptation. In some of the early experiments in the Tulane tilt chair the tendency of some subjects consistently to underestimate the vertical - that is, to make their judgments of the vertical in the quadrant of initial tilt - led the investigators to suspect postural adaptation. If adaptation occurred one could expect a shift of constant error in the direction of initial tilt and an increase in the number of underestimations of the postural vertical.

In order to test this, trials were made both in the modified link trainer and in the Tulane tilt chair. Comparison of judgments made by subjects when required to return themselves immediately from positions of tilt (no-delay) and when held in positions of tilt up to 65 seconds (delay). Significant increases of mean average and mean constant errors were recorded in the delay position, the constant error showed a shift in the direction of the quadrant of tilt, and there was an increased number of judgments made in the quadrant of tilt.

The Visual Framework

The extent to which a visual field influences postural judgment was investigated by the use of a tilting room containing a tilting chair, both of which could be tilted independently. Subjects were tilted laterally to positions of 45°R or 45°L; the room (visual target) was tilted to positions up to 20°R or 20°L. With the visual field remaining out of alignment with the gravitational vertical, subjects were required to return themselves to the gravitational vertical. Under these conditions of tilted visual field, the constant error of judgment increased to a maximum of 2°.

From the evidence presented from these experiments involving conflict between visual and somesthetic cues in the judgment of the postural vertical, it can be inferred that somesthetic cues are predominant. The tilting of the visual framework produces small but statistically significant shifts of constant error towards the quadrant of initial inclination. The shift is greater when the chair and the room are tilted in the same quadrant. The shift is small enough to warrant the inference that the tilted visual framework is a distracting element rather than a dependable guide in the judgment of the postural vertical.

THE PERCEPTION OF VISUAL SPACE

The artist is aware of the fact that horizontal lines appear to converge towards a vanishing point, and that upright lines always appear upright. Under the influence of a contrasting visual background, objectively upright lines may appear phenomenally tilted. The uprightness of objects in the physical world is as much a psychological problem as is their color, size, or perspective.

Under Normal Conditions

In a series of investigations using a modified Navy collimated star, it was found that judgment of the visual vertical could be made with a mean constant error of less than 0.5°. There was no significant difference in the judgment of the visual vertical and the visual-horizontal.

Under Visual Conflict

Under certain static and dynamic conditions objectively upright lines may appear tilted. Telephone poles and the walls of buildings seen against a steep slope may appear tilted in the opposite direction. The water in a narrow spillway parallel to a swiftly flowing brook appears to be running uphill, although as a matter of fact, it has sufficient slope to carry it through the spillway. Moore reports the perception of phenomenal tilt during the landing of an airplane. When the tail is down, the observer, on looking through the window on his side of the plane, sees the level field as horizontal. On looking across the aisle, the field, framed in the window which is sloping backwards at an angle of about 15°, appears to slope downhill.

The influence of a visual background upon the judgments of the visual vertical has been investigated by Gibson under the appropriate name of simultaneous visual contrast. A straight black line 30 mm in length was overlaid with a tiltable grille of parallel black lines. The grille was tilted at angles of 10°, 20°, and 45° in right and left quadrants. The line remained objectively vertical, but appeared phenomenally tilted in the quadrant opposite to the tilt of the grille. It was found that the contrast decreased as the angle of tilt of the grille was increased from 10° to 45°.

Wertheimer reported an experiment in which the subject observed a large mirror so placed that the image of a room appeared tilted at an angle of 45°. At first the room appeared tilted, but soon the room appeared upright and the floor horizontal. Wertheimer's explanation was that the lines of the mirror image became points of anchorage in visual space, and thus determined the phenomenal vertical and horizontal. Gibson and Mowrer report that while continued observation of the image made the tilted room appear more "natural," it remained tilted. "With effort, the subject could attempt to project himself into the mirror room and at such times it appeared still more 'natural,' less 'foreign,' 'artificial,' or 'wrong.' Such moments could not be maintained for long." They conclude that a "tilted visual field does not right itself under the conditions described and that possibly Wertheimer was reporting a relatively more cognitive phenomenon - the decrease in strangeness and unreality of the mirror scene."

Under Postural Conflict

It might be expected that a visual framework as labile as that suggested by Koffka and Wertheimer would be strongly influenced by body tilt. The validity and extent of such an influence is not apparent under normal conditions. The individual observing the main lines of visual space during head tilt, for example, while sitting at a table writing, either knows or assumes that they are upright and sees them accordingly.

Subjects tilted laterally to positions of 5°, 10°, 15°, and 20° in each quadrant while the room was tilted to 45° were required, while in a position of tilt, to return the room to the gravitational vertical. Each subject made 10 adjustments from each combination of positions - a total of 200 judgments. With the subjects in an upright chair position and the room tilted to 45° in right and left quadrants, the mean average error was 1.5°, the mean constant error 0.2°. At positions of body tilt of from 5° to 20° subjects reported a significant increase in average and constant errors with increase in magnitude of body tilt. The mean average errors range from 1.6° at 5° tilt to 2.9° at 20° tilt; the mean constant

errors from 0.4° at 5° tilt to 2.3° at 20° tilt. All judgments made with body tilted in the right quadrant and the majority of those made in the left quadrant were in the direction of initial room tilt. These results are in line with previous results on tilting which demonstrate postural adaptation with delay, in the direction of initial body tilt. As a matter of fact, much of the magnitude of the errors in setting the visual vertical might be attributed to adaptation. If this were so, one would conclude that a lateral body tilt of up to 20° does not seem to exert much effect upon the judgment of the visual vertical. No increase in variability of judgment with increase in body tilt was found; homogeneity of variance was demonstrated, and no significant difference in judgments was demonstrated for left or right quadrants.

VISUAL AND GRAVITATIONAL CONFLICT

The factors involved in space orientation when a horizontal centrifugal force is added to a vertical gravitational force have been the subject of investigation for more than a century. In 1820 Purkinje described in detail the effects produced while riding a merry-go-round, effects so striking and so vivid that one involuntarily leans towards the center "in order to bring the long axis of the body into line with the perceived vertical." Mach's interest in the problem led him to construct an experimental centrifuge for the purpose of measuring the phenomenal deviation of the true vertical under the influence of centrifugal and gravitational forces. From his results he concludes that, under these conditions, "one senses the direction of the resultant mass acceleration and regards this as the vertical." When a pendulum was suspended on the inside of his subject's car, he noticed that on two occasions the vertical was set at a compromise position, midway between the direction of the pendulum and the subject's body axis.

Studies using the human centrifuge produced results which confirm the findings of Mach. The equipment consisted of a power-driven human centrifuge with black-out car mounted in a nonswinging position at a distance of 20 feet from the center of rotation. A series of rotations in ascending and descending order was arranged at velocities of from 4 to 11 rpm with differences between successive trials of one rpm. These yielded values of the resultant force (Ø) of from 6.0° to 39.5° from the vertical. Subjects were required to set a luminous straight line (Navy collimated star, Mark II) to the true vertical. Three subjects participated in the experiment and made 10 judgments at each velocity, in ascending and descending series. The empirical relationship established by Noble's results between the values of Ø and the setting of the visual vertical corroborates Mach's hypothesis; viz., that under conditions involving horizontal centrifugal and vertical gravitational forces, subjects will set the visual vertical in the direction of the resultant mass acceleration. A statistical check was made on the empirical deviations of the mean settings at each velocity from Ø and in each case it was found that the differences could be accounted for by chance.

An additional experiment confirms these results. Using the same equipment and two velocities - 6 rpm and 10 rpm yielding Ø values of 13.8° and 34.3° respectively, subjects were required to maintain the visual target in the phenomenal horizontal position throughout a period of rotation of three minutes. The subject was brought to the maximum rotation within a period of two to three seconds, speed of rotation was maintained nearlyconstant forthree minutes, then the centrifuge was braked to a stop within three to four seconds. The line used as a target was connected to a transmitted selsyn, in turn connected to a receiver selsyn in the control room. Following cessation of rotation the subject continued to make the horizontal setting for an additional period of 200 seconds. The position of the phenomenal horizontal set by the subject was observed every five seconds throughout each trial. Three subjects made 10 trials at each velocity. Two important results appear in this experiment. In the first place, following acceleration there was considerable time lag in adjusting the line to the resultant force. The mean value of the lag was 73.2 seconds at 6 rpm and 89.1 seconds at 10 rpm. The lag following deceleration was relatively short, 35.0 seconds at 6 rpm and 23.3 seconds at 10 rpm. In the second place, once the lag was overcome the horizontal was adjusted during rotation to the resultant direction Ø, according to Mach's hypothesis, with no marked tendency either to overshoot or undershoot. Following deceleration, while the effect of rotation was wearing off, there was a tendency to overshoot, the error being of the order of two to four degrees.

It is evident from these results that when an individual is subjected to centrifugal force the visual target will shift phenomenally to correspond to the resultant of the centrifugal and gravitational forces. When this change takes place rapidly there will be a time lag; in other words, some considerable time must elapse before the change is manifested in the phenomenal visual field. A flier who is subjected to

rapid acceleration or deceleration over a short period will not experience the full disorientation effect, because there is not sufficient time for the manifestation to occur.

Mach has reported that the addition of a visual field tends to produce judgments of the vertical at an angle less than that of the resultant of the centrifugal and gravitational forces. This has been confirmed by investigators here and elsewhere.

We may infer from the experiments of Mach and from the results obtained in the Pensacola centrifuge that under conditions which involve the combination of horizontal centrifugal and vertical gravitational forces the individual will, in the absence of visual cues, shift the visual vertical phenomenally in the direction of the resultant of these forces. Moreover, when the change is made rapidly there will be a considerable time lag in the adjustment made to the resultant. When a competing visual field is added, the individual tends to project himself into the field and the adjustment of the visual vertical is a compromise direction between that of the main lines of the conflicting field and the resultant of the forces.

SUMMARY

The evidence presented supports the hypothesis that space orientation is a complex function involving, in the intact organism, all sense modalities that, under the circumstances, are appropriate. Moreover, it involves not only the receptor but the motor aspects of perception. The total effect of body tilting under static conditions or under the influence of centrifugal force is that the organism not only receives the impulses but reacts to them. With a tilted visual field there is a tendency towards postural compensation by appropriate motor responses. The perceptions involved in space orientation, both visual and postural, are motor as well as receptive.

When it comes to the experimental control of factors, there are certain difficulties apparent. It is not difficult to eliminate visual factors, and when this is done it is found that the individual makes postural judgments with a high degree of accuracy, both from positions of static tilt and under the influence of centrifugal force. The addition of a visual field produces compromise judgments, but the fact that a visual field influences judgment does not warrant the conclusion that it determines judgment. It is also true that in those experiments in which a rod must be set to vertical in the presence of a conflicting visual field, there is visual conflict, and with body tilt - whether due to static tilt or to centrifugal force - visual and postural conflict. The displacement of judgment produced when a visual field is added cannot be taken as evidence that the somesthetic cues are unimportant. Every flier of experience knows that, under certain circumstances, he faces the temptation to leave his instruments and fly by somesthetic cues; that this is a dangerous matter is admitted readily. It is evidence for the strength, albeit the unreliability, of the somesthetic cues.

The experimental control of somesthetic cues is difficult; their complete elimination is impossible. Thus, under all conditions of visual perception there is the added complex of somesthetic factors. It has already been pointed out that when these somesthetic cues do not enter into the solution of a visual perceptual problem, as in simultaneous visual conflict or in visual conflict uncomplicated by body tilt, the individual will neglect them. When body tilt, with its accompanying somesthetic cues, is added to the problem of visual conflict, compromise judgments of the vertical are made. It should be noted, however, that these compromise judgments are more variable than those made in the absence of the conflicting visual field. The arc of uncertainty is larger; they are made with less confidence than those made with somesthetic cues alone. Obviously, the most accurate judgments of the vertical are those made by the use of both visual and somesthetic cues and, if we accept the proposition that in visual perception there are motor as well as sensory components, these results would lead to the conclusion that the accuracy is due to the integration of somesthetic and somesthetic-visual cues.

It may be appropriate at this point to stress the fact that because events are never simple, because they cannot be totally observed at one and the same time, perception is a selective process. The selection of elements observed by one subject may differ considerably from those made by another, and if so, their descriptions of the event will differ. In order to use the descriptions of a number of subjects, it is necessary to ensure that they are all sufficiently sophisticated with respect to the conditions as to enable them to select the same elements for observation. If, for instance, one were interested in the identification of a bacillus, one would prefer the report of one individual highly sophisticated in this type of observation to the consensus of any large number of biologically naive observers. In the

experiments described in the preceding pages, it should be remembered that the observer is also what is to be observed; he is observing his own responses. The experimenter is performing merely a mechanical process of setting conditions and recording reports. What check, then, is there on the observations? In the first place, it might be expected that there will be consistency in the replicated observations of the same event by any one observer. In order to ensure this, it will be advisable to have each observer make many judgments under the same conditions. Secondly, one would expect that there would be consistency in the results of observers, comparably sophisticated with respect to what has to be observed and observing under comparable conditions. In experiments where such consistencies do not occur, it might be safer to ascribe the wide variability to unequal sophistication of observation rather than to individual differences.

The selective nature of perception is especially important in those experiments in which perceptive conflict occurs. In the experiments on visual conflict, those involving simultaneous visual contrast and those involving a tilted field, the problem faced by the observer is that of placing a line or rod in a position conflicting with that of the visual background. Unless he has positive awareness that somesthetic cues will assist him in his problem, there is little reason for the subject to select from somesthetic cues when he makes his decision. To say that he places a rod in what he "feels" to be the upright is merely playing upon words. Even though he has an unusual tilted background, he still has standard visual guides to the true vertical in the boundary formed by nose, cheeks, and supra-orbital ridges. In the normal sitting or standing positions, ones which do not involve a change of gravitational forces, these visual cues are likely to be more useful than somesthetic cues when the problem is one solely concerned with visual conflict.

The determinants of the visual vertical are, according to the theory of Wertheimer and Koffka, the main lines of the visual framework. Thus, if the whole visual field of the observer is tilted, verticality and horizontality are altered correspondingly. This neglects the obvious experimental finding that there is never complete acceptance of the tilted visual field; there is always motor response accompanying the perception which produces the tendency to correct the false visual impression by postural compensation. Moreover, while the eyes are flexible, they are not completely labile. Their limits of mobility are presumably concommitant with the needs of a fairly symmetrical organism which is, under normal conditions, able to maintain a postural upright without the aid of visual cues.

Gibson and Mowrer believe that "visual orientation presupposes postural orientation. Once orientation to gravity is granted, visual cues can make their contribution both to postural and to the uprightness of seen space; they become specific." They believe that because of the priority of gravitational factors, the visual framework can be automatically corrected during body tilt.

The labile visual theory proposes that visual perception is a process concerned primarily with sense reception. If the main lines of the visual groundwork are altered, enclosed visual elements are thereby altered. More in line with the experimental results is the theory which regards perception as a discrimintary response involving both sensory and motor functions; the alteration of the visual framework produces automatically a postural as well as a visual response. Orientation to space, visual and postural, is the outcome of an integrative function - one which involves not only the receptor organs but motor discriminative responses as well.

* * *

ACCELERATIVE FORCES

SOME CHARACTERISTICS OF VESTIBULAR EYE MOVEMENTS*

George R. Wendt
University of Rochester
Rochester, New York

INTRODUCTION

We have accumulated, in our laboratory, a good deal of information about eye movements which is not generally known. The data which, I believe, will be of particular interest to you are those from highly magnified records of vestibular nystagmus. We record eye movements through closed lids by means of the Dodge mirror recorder, thus excluding the visual factor. This recorder presses a little wooden cube—pivoted so as to turn—against the closed lid over the apex of each cornea (Figure 1). As the eyes rotate the cubes stay tangential to the cornea. A mirror on each cube reflects a band of light to a photokymograph, yielding tracings of the eye movements on a moving strip of sensitive paper. This device gives us 4 to 5 mm of movement on the record for each degree of eye movement - a very highly magnified record.

George R. Wendt received his B.A. from the University of Rochester and his M.A. and Ph.D. from Columbia University. He taught psychology at Yale University, University of Virginia, and University of Pennsylvania. Dr. Wendt became Chairman of the Psychology Department of Wesleyan University in 1939 and of the University of Rochester in 1945. Director of various military research projects on the selection of aircraft pilots and the prevention of motion sickness, he also has been Associate Editor since 1946 of the Journal of Experimental Psychology and of the Journal of Comparative and Physiological Psychology.

Certain unpublished facts arising out of our research during the past 20 years are as follows:

a. When seated with head fixed, in the dark, or with eyes closed, normal subjects usually show some degree of spontaneous horizontal nystagmus. We have called this a "drift" or an "imbalance."

b. After a single acceleratory stimulus, there is not only the primary nystagmus, with which everyone is familiar, but following this there is a weak but long-lasting secondary nystagmus in the opposite direction. We are in the midst of a study of its quantitative characteristics.

c. The primary nystagmus shows certain lawful relations of its speed, duration, and time-course to the stimulus given to the ear. The nature of some of these relations will be presented.

d. A visual field inhibits vestibular eye movements. We have studied the amount of inhibition and its speed of development or loss.

e. So-called "habituation to rotation" can be prevented by control of orientation. This is convenient for the student of nystagmus, and also promises to tell us much about the relation of orientation to personality structure.

OCULAR DRIFT

Many, or perhaps all, subjects when sitting with fixed head and vision excluded show a continuous slow drift of the eyes. Our recorders pick up only the horizontal drift, but other drifts may be there.

---

*ONR Project NR 143-060, Contract N6ori-126 T.O. 1

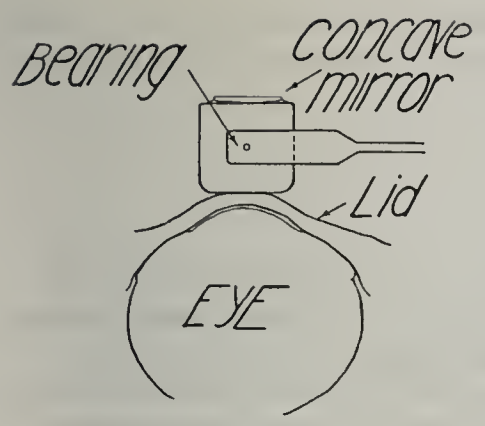

Figure 1 - Cross-sectional view of eye and closed lid with mirror recorder for photography of eye movements through closed lids shown in operating position. The pivoted wooden cube maintains a tangential relation to the underlying corneal surface.

At high magnification of recording this drift may be immediately evident on the records. In subjects known to be perfectly normal, the eyes may drift as fast at 0.5° per second. All drift rates below this, down to zero drift, are encountered. In some subjects the drift is consistent from day to day. Dr. Hauty used the same subject almost 100 times and found a drift always in the same direction, although greatly variable in rate. In other subjects the drift may be to the left one day and to the right the next, or it may change during an experiment. A drift may be brought on by rotational stimulation.

This is about as much as we know about this matter. More research is needed. The normal drift is probably related to allegedly abnormal phenomena reported in the literature, variously called "readiness for nystagmus," "vestibular disharmony," and "directional preponderance of nystagmus."

The source of such a drift may be peripheral or central. If you cut an eighth nerve in man, you get a strong drift when the eyes are closed (a spontaneous nystagmus) which I have recorded several months after the operation. Since such drift is due to a peripheral deficit, it suggests that normal ears perhaps differ in their base-line of activity. On the other hand the active centers in the vestibular nuclei may differ on right and left, thus producing an "imbalance" of output to the motor nuclei of the eyes; or, if we follow M. H. Fischer in believing that stimulation gives rise to alternating phases of nystagmus lasting up to one hour, we might attribute the drift to the residuals from stimulation by head movements before beginning the observations. Finally, one might hypothesize an effect of higher centers; although I doubt this because the drift is so steady. Now what is the practical importance of this? Those of you who work on autokinetic movement or oculogyral movement may wish to take into account that these drifts can cause you trouble. I would surely expect an active drift to cause apparent movement of a spot of light. The presence of the drift and its character also have important consequences for the theory of the vestibular apparatus.

SECONDARY INVERSE NYSTAGMUS

When you accelerate a subject and then hold him at a steady speed, or decelerate him and then let him sit quietly, the eyes move for at least several minutes. At the beginning of the response is the primary nystagmus which everyone knows. This gradually slows to a stop and immediately the eyes begin to drift into a nystagmus in the other direction - the secondary inverse nystagmus. Usually this speeds up for a time, then slows down and finally stops after three minutes or more. Sometimes it slows down but does not stop - at least within the time limits (up to 30 minutes) that we have recorded. Or it may be replaced by a third phase of nystagmus, opposite in direction to the secondary. We believe, but cannot yet prove, that these secondaries which apparently do not stop simply go into a spontaneous drift; and that those which reverse into a third phase do so because of the reestablishment of a drift in that direction.

We have extensive records of such secondary nystagmus from both humans and monkeys, normal and operated, and under the influence of alcohol. However, most of them have not yet been analyzed.

Dr. Hauty is now engaged in a quantitative study of the secondary nystagmus. Here are some preliminary data.

a. The fastest speed of the slow phase in the secondary nystagmus, among the records he has measured, is about 7° per second. By contrast, the fastest speed of the primary nystagmus in the records of the same subject is about 80° per second - about a 10:1 difference.

b. The total amount of eye movement or, rather, the total amount of slow phase in the secondary nystagmus is about 1/4 to 1/3 of that in the primary nystagmus which preceded it. Whereas Hauty's most productive subject put out 1200° of eye movement in the primary nystagmus when rotated at one turn in two seconds, the same subject in the biggest secondary nystagmus put out only 400° within the five minutes following the stimulus.

c. The speed of the eyes in the secondary nystagmus shows regular cyclic variations. The length of these cycles is apparently the same as the normal duration of the primary nystagmus. This is an intriguing finding on which I shall comment later.

PRIMARY NYSTAGMUS

Dr. Hauty has just finished a quantitative study of the primary nystagmus. He built a device by which the speed of rotation and its acceleration could be satisfactorily controlled. Subjects were rotated at each of five speeds, from the extremely slow speed of one rotation in 30 seconds to the moderate speed of one rotation in two seconds. Six accelerations were used, once with each speed, from the near threshold acceleration of 1°/sec/sec to 360°/sec/sec. The speed of slow phase of nystagmus in each part of the record was then laboriously measured. Dividing his record into 2-second segments, Hauty measured the total amount of slow phase in each segment. This gave him the total displacement in the segment, or, if you wish, the average speed of slow phase during that time. These displacement figures were then summated in an accumulative graph (Figure 2) for the entire primary nystagmus - the

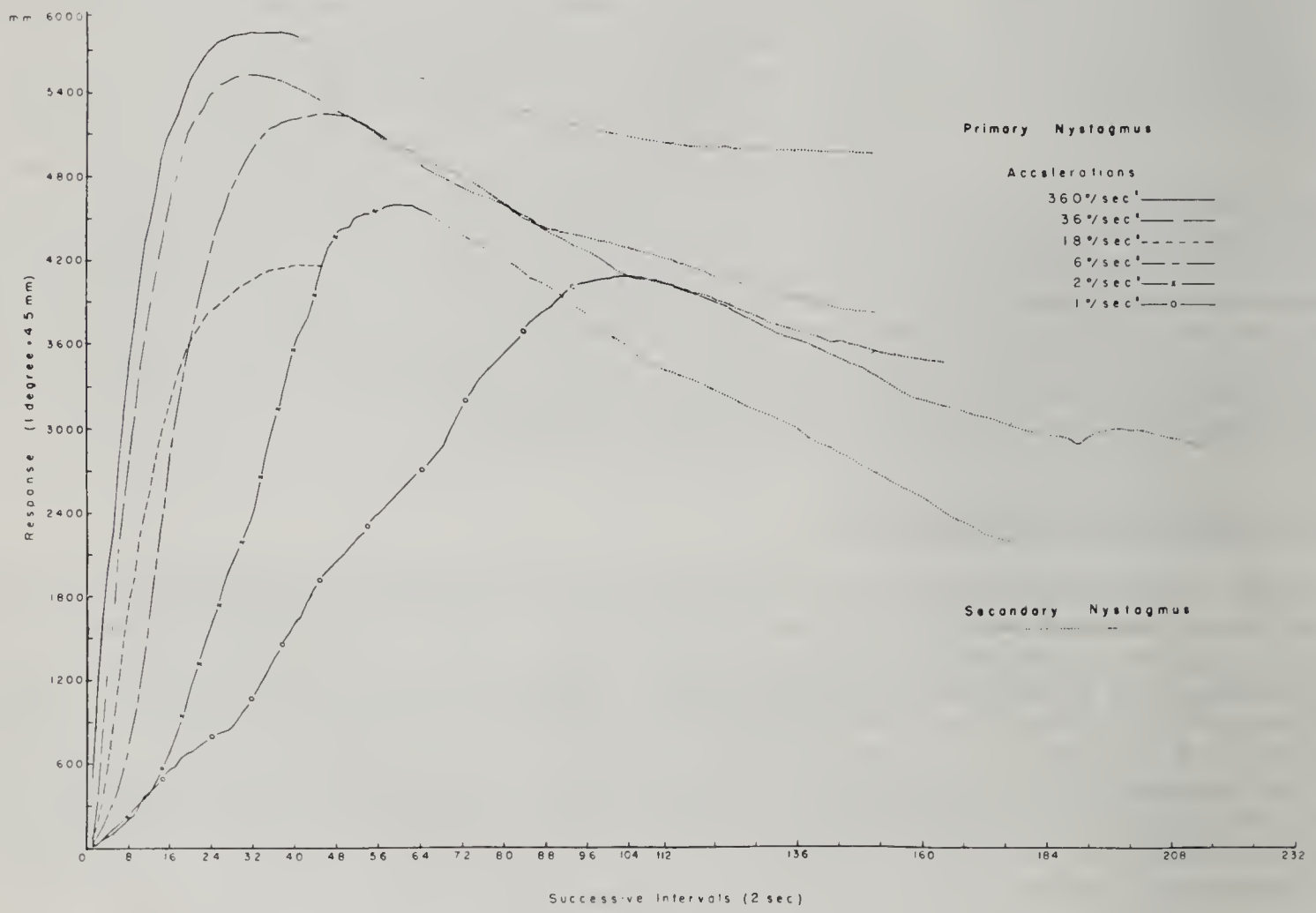

Figure 2 - Accumulative output - 180°/sec velocity

ascending limb of the graph - and later for the secondary nystagmus - the descending limb of most of the graphs. He thus obtained a continuous graph of the slow phases, omitting the fast phases from consideration. The slope of any portion of such a curve shows the speed of the slow phase; the total height of the curve shows the total amount of slow phase during the primary nystagmus; the time to the reverse of the curve shows the duration of the primary nystagmus. The top curve shows that the primary nystagmus lasted for about 32 of these 2-second segments; its duration was 64 seconds. The total amount of movement for this record was almost 6000 mm, which means about 1200° of rotation of the eyes. The course of speed of the eyes shows an accelerating decrement. This is the uniform kind of response to a quick acceleration - in this case one-half second long, or 360°/sec/sec.

At the lowest acceleration, 1°/sec/sec, which here lasted 180 seconds to reach a speed of 180°/sec, the speed of the eye movement was very much less as shown by the slight slope of the bottom graph. Note that as long as the subject was accelerated the nystagmus lasted, but then it stopped and reversed.

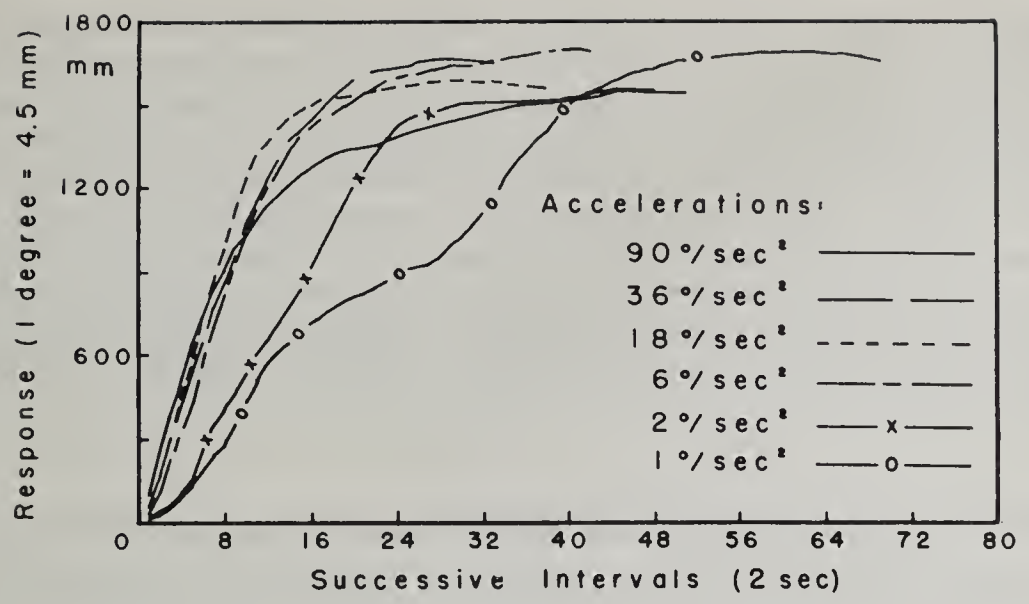

Figure 3 - Accumulative output - 45°/sec velocity

Note also that the total amount of eye movement is less than that for the top graph—only 4000 mm as compared to 6000 mm. I will continue the discussion of this curve later.

Figure 3 is the same as Figure 2 except that a slower speed was used - one revolution in 8 seconds or 45°/sec. Note that the graphs resemble each other except that there is less response, the maximum being about 1600 mm.

Due to a lack of time for a full discussion of the data, I shall have to give you Hauty's main findings as a series of assertions.

a. The relation in Figure 2 between total output (height of the curves) and acceleration level (the less acceleration, the less the total output) is true for only strong stimuli, i.e., high velocities. At rotation speeds of 45°/sec and below, all accelerations produce the same amount of eye movement.

b. The total amount of eye movement is directly related to the total power expended on the ear, i.e., to the speed of rotation used. Dr. Hauty found that a graph of the total eye movement at each velocity of rotation was a straight line; the less the speed of rotation, the less the output of eye movement (Figure 4). The slope of this line was such that output of eye movement decreased a little less rapidly than the decrease in power expended. Reducing the power to 1/15 reduces the eye-movement output to 1/10. He concludes that input to the ear and output from the eyes are directly related.

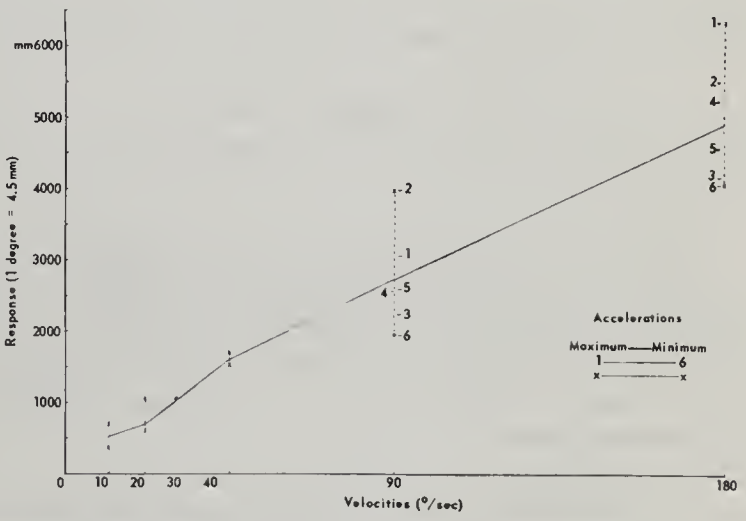

Figure 4 - Total response output at each velocity level

c. His next finding, while not new, may come as a surprise to some. The duration of the primary nystagmus is nearly a constant, unaffected by how fast you rotate. As long as the acceleration is brief, the nystagmus duration is very nearly a fixed figure whether it is a vigorous nystagmus totalling 6000 mm or the feeble nystagmus only 1/10 as fast resulting from a speed of 12°/sec. Buys had found this some years ago; and Hauty and I got the same result in the summer of 1949 using oculogyral movement as the indicator of nystagmus. The present highly magnified records now appear to confirm it.

d. On the other hand the duration of the primary nystagmus is lengthened by increase in the duration of acceleration. After long accelerations, the eyes stop soon after the end of the acceleration. They may even stop while the platform is still accelerating. (This argues against a wholly peripheral explanation of duration of nystagmus.) The general principle seems to be that the period of decrement in nystagmus is a constant. Hauty found that the point of inflection on graphs of speed-of-eye movement was a constant time before the end of the nystagmus.

e. Observing the bottom graph of Figure 2, we note a curious and unexpected result. Although the acceleration was constant for all 3 minutes, the speed of eye movement showed a regular cycle of fluctuations. The same cycle is present in all of the graphs. The length of these cycles is the same as the duration of nystagmus after brief accelerations. This is an interesting result, and we feel that we have something important. I must confess that so far we have not wished to say too much about what it means; but we are working on it. Note that the same cycle shows up also in the secondary, which inclines us to look for an explanation by central mechanisms. We have not yet had an opportunity to see whether it occurs also in the spontaneous drift, but are inclined to predict that it will. The duration of nystagmus is apparently a function of some centrally conditioned rhythmic process. It is obviously necessary to compare these cycles directly with other excitability rhythms, such as those of the knee-jerk.

EFFECTS OF VISION ON VESTIBULAR NYSTAGMUS

Our eye-movement records are taken through the closed lids of the subject. Much research of other investigators is done with open eyes in a lighted room. Vision then facilitates or inhibits eye movements. Such data in our opinion have led to much misunderstanding.

Some years ago I published data showing that the eyes, during a short turn of the head, 65°, showed a total output of about 40°, which is a response 60 percent as large as its stimulus. With one eye seeing the surrounding, and thus reinforcing the nystagmus, the response was 80 percent adequate. But, with one eye seeing a fixed field rotated with the subject, the response was only 5 percent adequate. In general, the inhibition was most complete when the nystagmus was weakest.

In the summer of 1949 Dr. Robert Brown and Mr. Burton Andreas, working in our laboratory, determined that it took about 1-1/2 seconds for a visual field to supress a weak nystagmus. The subject had been rotated in the dark, one eye open, and suddenly a fixed field was lit up. This was the inhibiting stimulus. On darkening the field again the nystagmus was fully reestablished in about 3/4 second.

These inhibitions were produced by a good visual field. We have not worked on the possible inhibiting effects of weak visual fields, such as the spot of light used in experiments on autokinetic movement, or the collimated star used by Capt. Graybiel. The data of such experiments, being quite similar to our data on eye movements recorded through closed lids, indicate that these weak fields have minimal inhibitory effects. However, the data of certain investigators who observed nystagmus through a lens, hoping thereby to avoid visual inhibition by blurring the field, do not correspond with our results obtained with vision excluded. We are inclined to attribute the differences to inhibition.

PREVENTION OF SO-CALLED "HABITUATION TO ROTATION"

In 1923 Dodge studied habituation of post-rotation nystagmus and concluded, probably correctly, that one learned to inhibit nystagmus by use of visual fixation. Such habituation to rotation is a well-known phenomenon.

In 1934 I found that so-called "habituation" with closed eyes was not habituation at all, in the usual sense of a gradual decrement of response. Instead it was the replacement of vestibular control of the eyes by another system of control, in which the eyes wander in an irregular, nonconjugate fashion. This material was published in such a place that students of vestibular functions have mostly been unaware of it. I want to call it to your attention because this knowledge can save you a lot of trouble and aid in interpretations.

First let me describe the character of the intruding system of eye movements which competes with and replaces nystagmus. I have studied this in humans and in several species of monkeys. "Habituation" occurs as a competition between the vestibular reflex and another system of control of the eyes. This system consists of an autogenous wandering of the eyes in a nonconjugate manner such as has been described in states of sleep, unconsciousness, or coma. The reflex and this system compete for control in an almost "either-or" fashion. There are usually sharp transitions, bilaterally simultaneous, from nystagmus to wandering movement and from wandering movement to nystagmus.

The first appearence of these periods of nonconjugate movement, during a series of rotations, is usually in that portion of a reponse when nystagmus is weak, as at the end of the primary phase of nystagmus. With continued stimulation it encroaches further, or it may appear several times during the course of a prolonged nystagmus. The records resemble, in abruptness of the rivalry, those taken when strong rivalry is introduced and withdrawn, except that the onset of the wandering movement is sharper than is the onset of visual inhibition.

Not all records show complete dominance of the wandering movement. In some there is some breaking through of the nystagmus.

If the stimulation is an oscillating rotation, the wandering movement may show a rough congruence with the phases of oscillation, totally unlike the reflex, but nevertheless influenced by the stimulus.

With respect to the question of how habituation can be prevented, some long-unpublished data are presented.

Subjects were repeatedly rotated, with eyes closed, through a short arc of 65° or less. Under these conditions, unless special measures were taken, habituation occurred in the manner you have already seen. I was interested in the factors which might prevent this. Altogether I used 102 subjects and various kinds of instructions to find out.

Maximum habituation occurred when the subject received no special instructions. All of the other instructions used lessened habituation: instructions to attend to a buzzer, instructions to attend to the rotation, instructions to make various voluntary responses to the rotation (look up, look to the right, move head, prevent eyes from moving).

Habituation was also reduced by use of visual reinforcement and by altering the character of the stimulus.

In addition to these experimental data we have many observations which might be classed as "clinical." We have been rotating both humans and monkeys for about 20 years and have learned that such loss of eye movements can be prevented with many subjects. On the bases of this experience we have developed an hypothesis regarding the mechanism of this habituation. It has not been experimentally tested beyond the data I have given, but, nevertheless, I hold it with a considerable degree of confidence. This is the hypothesis: I believe that nystagmus is present when the subject is oriented toward the environment; and that the wandering movement is present when he is oriented toward his body or toward thought, revery, or fantasy.

When monkeys are used for subjects, any strange sound (clicking the finger nails, watch tick, rubbing the hands together), or other stimuli such as blowing lightly against the face, or bringing a piece of banana to the nose, will restore nystagmus immediately. Closing his nostrils with the fingers is a sure way to do it.

With humans one can get good results by a combination of such methods, and by the use of instructions, which emphasize external orientation of attention. They should be told to stay alert, to be aware of the experimenter, to attend to sounds within the room, or to stay stimulus oriented. Hauty has them imagine a ship on an imaginary horizon; and for most subjects this prevents habituation for awhile. Some, like Hauty's 100-times subject, can prevent it at any time; others cannot prevent it.

With the eyes open, as in the experiments on oculogyral movement during and after rotation, very little habituation occurs. This would be expected, according to our hypothesis, since the subject is then furnished with an external reference. On the basis of my early eye-movement studies of visual reinforcement, I would expect that in the presence of such an external reference only an occasional intrusion of the wandering movement would occur in the case of human subjects. Rhesus monkeys, on the other hand, often withdraw and show wandering eye movement even in the presence of a visual field. Green monkeys tend to stay alert to their surroundings.

Much more could be said about this, were there time. Our facts are related to many others. Especially interesting are the personality correlates of the ability to stay externally oriented. I have been astonished at the large number of researches in psychiatry, neurology, clinical psychology, personality, and psychophysiology which are related to our data. Some of our students at Rochester are getting interested in this matter and in its relations both to personality and to susceptibility to motion sickness. This work is in progress and not yet in shape to report. I hope soon to have further data.

* * *

STUDIES TO DEFINE QUANTITATIVELY THE STIMULUS REQUIRED TO PRODUCE MOTION SICKNESS*

Walter H. Johnson
Defence Research Medical Laboratories and
RCAF Institute of Aviation Medicine
Toronto, Canada

Walter H. Johnson received his B.S. from McGill University and his Ph.D. from the University of Toronto. He has held positions as Teaching Fellow in Physiology at McGill University, as Assistant Professor of Physiology at Georgetown University, and as Assistant Professor of Biology at the University of Western Ontario. Currently he is Chief of all research on motion sickness being conducted by the Canadian Department of Defence at the Defence Research Medical Laboratories, Toronto.

INTRODUCTION

It has been established that the nonauditory membranous labyrinth in the head is the essential sense organ for motion sickness. Evidence for this comes from the fact that surgical removal of the organ in dogs results in immunity to this malady (12). In regard to humans, it is significant to note that subjects with eighth nerve deafness are immune to motion sickness (12).

Although adequate stimulation of this organ resulting in motion sickness has been induced in the laboratory by many different mechanical devices, there exists considerable lack of agreement as to the essential nature of the adequate stimulus (9, 7, and 12).

From studies employing the human centrifuge, it became apparent that an acute vertigo associated with marked motion sickness follows movement of the head in space which gives rise to a gyroscopic precession (10). This phenomenon was associated with a completely false sensation of movement. Movement of the eyes independent of the head did not produce this effect. This precessional effect, imposing one angular velocity upon another, has also been reported by McIntyre (8) as being a very effective means of inducing nausea and vertigo. Spiegel (11) also noted the effectiveness of such combinations of rotations in inducing sickness when using the Barany chair.

PROCEDURE AND METHODS

For the purpose of this study, an instrument called the gymometer (4) was designed to measure, graphically, angular velocities in the three orthogonal axes. By turning a switch, these quantities are integrated to record the resultant gyroscopic moments about any particular axis and the vectorial sum of their moments (gyroscopic precession). The instrument not only measures the magnitude but indicates the true character of the motion studied.

Initial studies were made confining the motion applied to the body, as a whole, to one of simple harmonic motion limited to one orthogonal plane with the body position fixed. The angular velocity in the other two orthogonal planes was kept as close to zero as possible and, consequently, the precessional stimulus applied to the body as a whole by the apparatus likewise approaches zero. This is the situation used in this experiment and produced by a simple single-pole swing (radius 15 ft, arc 70°, period 16 cycles per minute) constructed to minimize any lateral movement (framework composed of angle iron). In initial studies the swing was hand propelled, but eventually it was motor driven by applying a force just sufficient to overcome the friction of the bearings, and that due to windage, by way of a

*By invitation

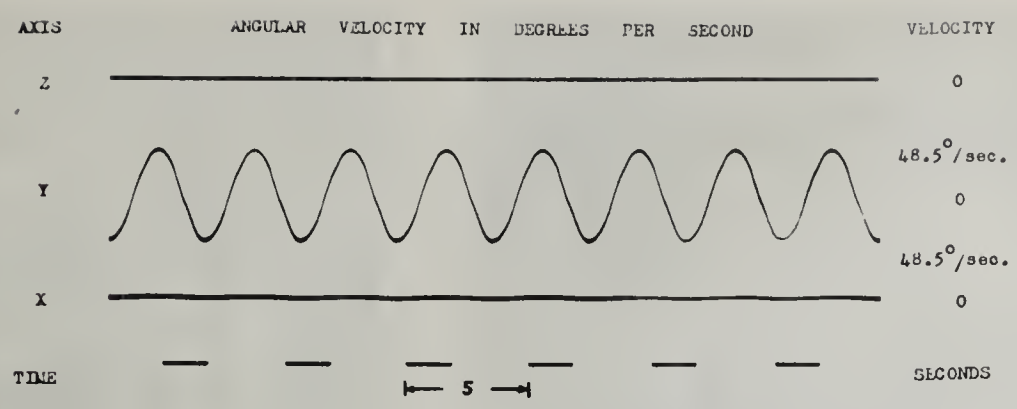

Figure 1 - Gymometer recording showing motion of the motor-driven swing

torsion spring connection which, by eliminating irregularities of the motor, imports a relatively uniform response similar to that of a simple pendulum (Figure 1). When the reverse record is superimposed on the original, it is found that except for a slight yawing action, the motion of the swing closely approaches simple harmonic action.

The value of the gymometer in analyzing the motions of swing was quite evident in preliminary research when a rope swing (radius 10 feet, period 17 cycles per minute, arc 60° to 90°) was used to induce sickness in experimental animals (cats). This swing had two undesirable motions as far as simple harmonic motion was concerned, namely an appreciable yaw in the horizontal plane and a consistent irregularity in angular velocity in the vertical plane, the latter due to the fact that it was hand propelled (Figure 2). These findings suggest that some swings used elsewhere in studies of motion sickness produced unsuspected but measurable angular velocities in the horizontal plane which would have been apparent had such an instrument as the gymometer been available.

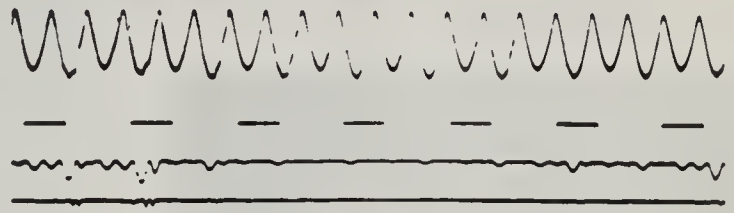

Figure 2 - Gymometer recording showing unavoidable yaw in the horizontal plane when the rope swing was used. Also note consistent irregularities due to hand propulsion.

As indicated above, it is obvious that if the true stimuli of any motion actually could be measured, it would be necessary not only to control the over-all motion imposed on the subject's body but also any concurrent motion of the subject's labyrinth (head). To accomplish this it is necessary to measure the head movement in order to assess the true over-all stimuli resulting from the experiment. At the present time this has been possible by using human subjects only. Since the original gymometer weighs about twenty pounds and can not conveniently be fastened to the subject's head, a less-massive model is contemplated. In this preliminary study, however, head movements have been recorded mechanically in the following manner. A linen thread passing through a pulley connects the subject's head to a pen which records the movements on graph paper rotating on a kymograph (Figures 3, 4, and 5). The recording is roughly calibrated by first deliberately tilting the head forward through ten degrees. The atlanto-occipital joint is taken as the fulcrum for these movements. The subject wears a pair of opaque goggles and is instructed to keep his eyes closed to eliminate willful interference. It is felt that the head movements recorded constitute a measurement of vestibular sensitivity.

RESULTS

The recording of head movements of RCAF Flight Cadets showed that there are variations in the ability of different people to control their head movements during angular accelerations of the body in its sagittal plane. It is interesting to note (Figure 6) that although three different individuals were subjected to identical conditions of swinging, the one who showed the least independent head movement has a history as being very resistent to motion sickness; whereas the subject who showed the largest head movement is very susceptible to airsickness. Furthermore, the latter feels that he is able to overcome sickness by resting his head on some immovable part of the aircraft.

Figure 3 - Side view of subject in swing showing method of recording head movements on a kymograph

Figure 4 - Front view of subject on swing

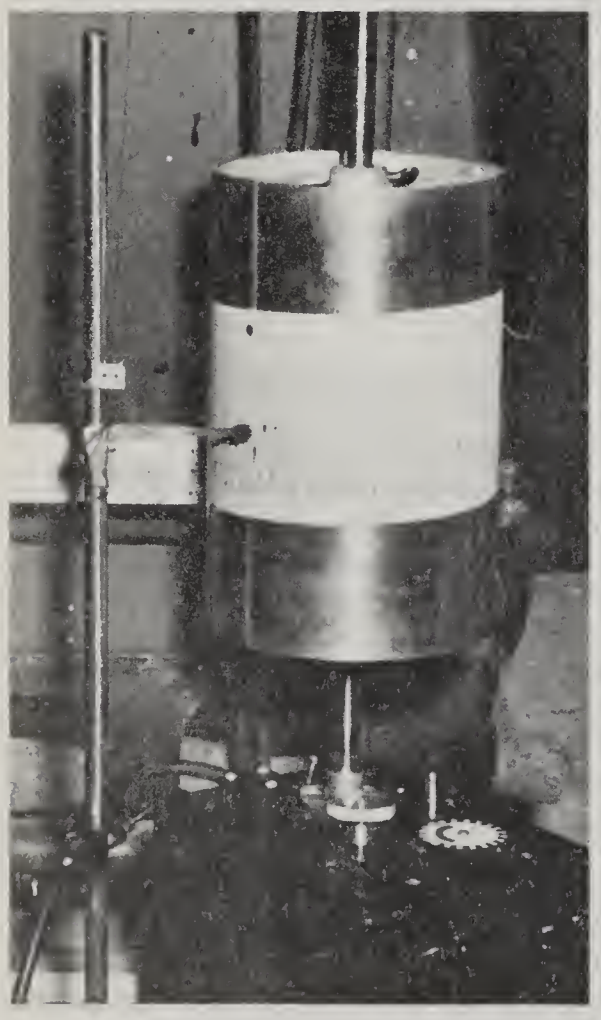

Figure 5 - End view of swing showing kymograph behind seat

The next available subject was a Naval air cadet who had been sick on the accelerator (human centrifuge). When tested on the swing, he vomited after three minutes and his independent head movement was as pronounced as in the above-mentioned sensitive case.

These preliminary observations indicated the desirability of a large number of observations in order to determine whether or not such differences might be due to chance.

From January to March 1950, there were recorded 108 measurements of head movement of subjects obtained largely from a group of incoming flight cadets. Their mean head movements on the swing, when the arc was 70°, ranged from 4 to 40 units.* Twenty-three percent of these subjects, having a mean nodding head movement of 16.7° as contrasted with 7.2° for the nonsick group (Figure 7), showed symptoms of sickness within six minutes on the swing. On comparing these means and the standard error of the difference between them, a probability ("P" value) of less than 0.01 was found, showing that the magnitude of head movement independent of the swing indicates one's susceptibility to swing sickness (Table 1).

The importance of these independent head movements was further emphasized when they were prevented. Of 27 subjects who had vomited when the head was free to move, 24 showed no symptoms when exposed to identical swinging as before but with the head held by a strap passing around the forehead from the back of the seat.

*One unit represents a vertical displacement by the recorder of 1/10 inch.

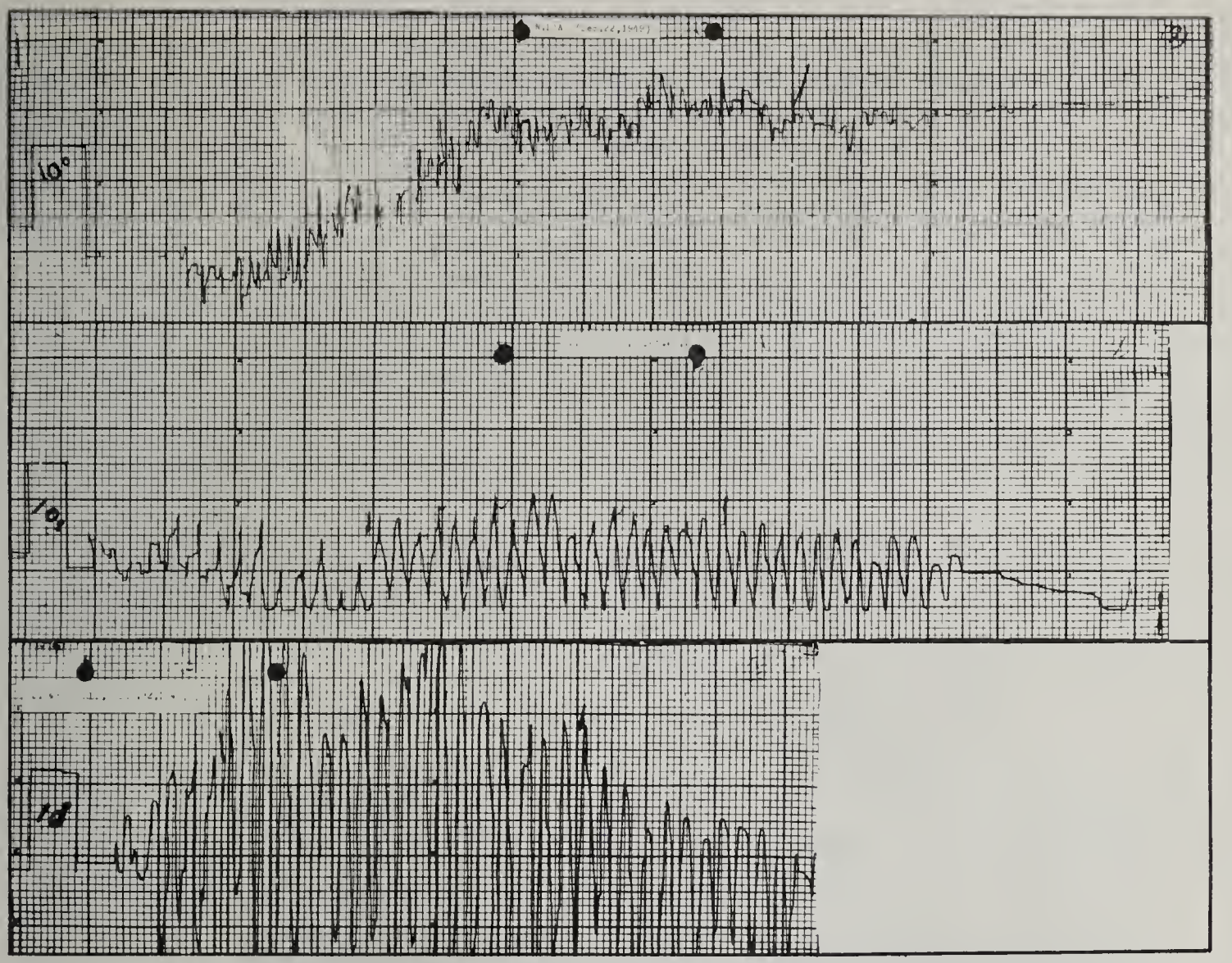

Figure 6 - Recordings of three different subjects' head movements, independent of the swing, while being swung through an 80^0 arc with a period of 16 cycles per minute. The swing was hand-propelled.

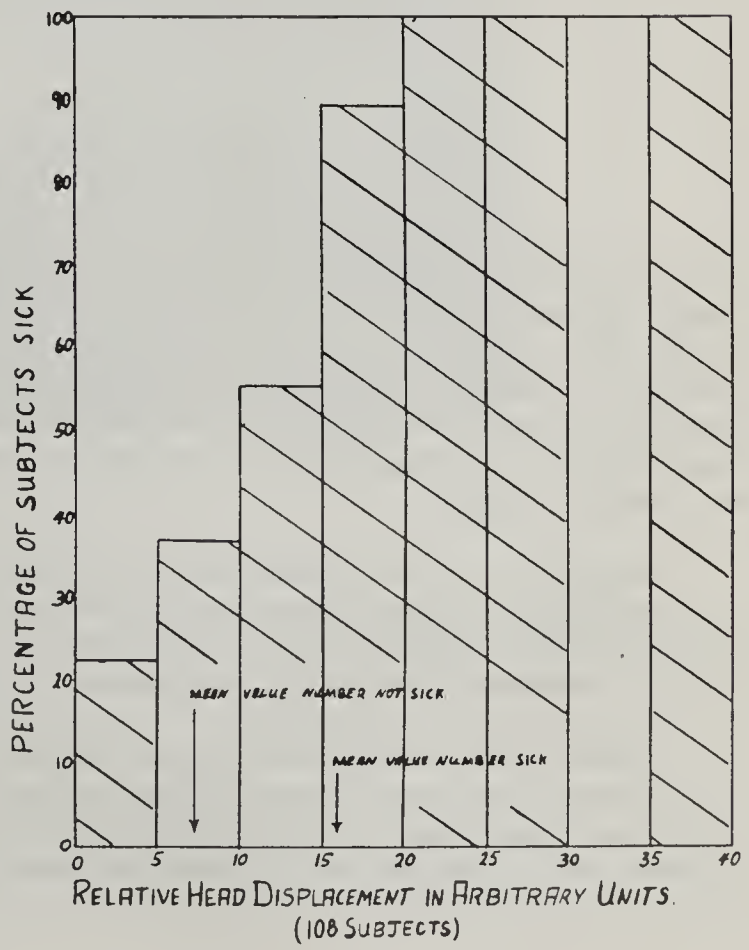
PERCENTAGE OF SUBJECTS SICK
MEAN VALUE NUMBER NOT SICK
MEAN VALUE NUMBER SICK
RELATIVE HEAD DISPLACEMENT IN ARBITRARY UNITS.
(108 SUBJECTS)

Figure 7 - Incidence of sickness relative to head replacement

TABLE 1

Relation of Head Movement to Sickness Incidence
on Simple Harmonic Swing - Hand-Propelled
(6 minutes at 16 cycles per minute)

Reaction	Number of Subjects	Mean Head Movement (arbitrary units)	S.D.
Sick	29	23.63	14.82
Not sick	79	11.15	4.15
Standard Error of Difference: 4.58 t = 2.78 Probability of Difference: < 0.01			

TABLE 2

Relation of Head Movement to Sickness Incidence
on Simple Harmonic Swing - Motor Driven
(6 minutes at 16 cycles per minute)

Reaction	Number of Subjects	Mean Head Movement (arbitrary units)	S.D.
Sick	28	12.64	8.35
Not sick	52	7.3	4.18
Standard Error of Difference: 1.58 t = 3.38 Probability of Difference: 0.01			

The results reported above were obtained with hand propulsion of the swing. Use of the motor drive to produce a more uniform motion of the swing resulted in similar conclusions (Table 2). On comparing the amplitude of head movements as a result of the two different methods of propulsion, it was evident that these were consistently less when the swing was motor driven and yet the incidence of sickness was higher (38 percent as compared with 23 percent). The results thus suggest that it is not the over-all independent movement of the head which determines swing sickness but that there is some fundamental component of the head movement which is greater among the susceptible subjects.

Tests were also carried out as to the effects of fixing the head to the swing when the swing was motor driven. A group of 100 subjects with the head free to move showed an incidence of 37 percent sickness while another group of 100 subjects under identical motions of the swing, but with the head fixed to the back of the seat by means of a strap around the forehead, showed only 5 percent sickness.

Experimental animals also gave evidence in this regard. Five dogs, each of which was very susceptible to motion sickness, all consistently vomited on a swing within 30 minutes if the head was free to move; but none of these animals became sick within 75 minutes when the head was in the same relative position as before but fixed by means of braces. In regard to cats the same conclusion was

reached after five such tests were made at the Institute on each of ten susceptible animals. The cats consistently vomited when the head was free; but they never vomited under identical movements of the swing when independent head motions were prevented, either by supplying braces to the head and neck or by placing the animals in such tight quarters as to prevent any head motions independent of those of the swing.

DISCUSSION

It is indicated that the results reported here establish a new method of investigating relationships between individual susceptibility to motion sickness and the types of motion responsible. A search of the literature reveals findings which have been given a different interpretation, but which actually support the conclusions here presented. Thus Wendt (13), who was able to make his subjects sick by vertical accelerations and decelerations, did not securely fix the head; while Manning (5) was unable to cause sickness in an elevator when the head was fixed (which was done in order to maintain the position of the membranous labyrinth relative to the planes of space). Also, Morton et al. (6) were able to induce sickness in subjects who simply stood or sat on a stool in an elevator.

It might be surmised here that since pilots seldom become airsick except when being carried either as passenger or as co-pilot, their resistance is due in part to the fact that they constantly refer to the horizon, i.e., their head maintains a more steady equilibrium in spite of the pitching and rolling movements of the aircraft in rough weather. A pilot's resistance to sickness during aerobatics may be the result of the fact that, since he accurately foresees the movements of the aircraft, those of the head relative to the movement of the aircraft are less independent.

It is hoped that we now have a brief test (it takes only about 7 minutes to perform), which will enable the Air Force to select those who are most likely to become airsick and those who are not. However, many more observations will have to be made; and this is being accomplished by having the tests performed on flight cadets in the course of their medical examination at the Institute, following which records will be obtained as to their susceptibility to airsickness while in training.

Figure 8 - Movement of small light attached to top of helmet on subject in swing. Camera, fastened to swing, was left "open." Both lateral and nodding movements are seen.

It is now planned to record the head movements in the three orthogonal planes simultaneously and to resolve the forces concerned. To do this a light-weight gymometer is contemplated which can be incorporated in a helmet for this purpose. Some preliminary tests, however, have been made in this regard to determine the pattern of the head movement (Figure 8). It is seen that the lateral head movements at right angles to movements in the sagittal plane are relatively small. However, it may be that the product of the two gyroscopic moments constitute important stimuli for motion sickness. In this regard, it is known, as mentioned above, that violent labyrinthine stimuli can be induced by superimposing one angular momentum upon another. As also indicated by Armstrong (1), "A special type of angular acceleration which is important in aviation is that which occurs when an active movement of the head is

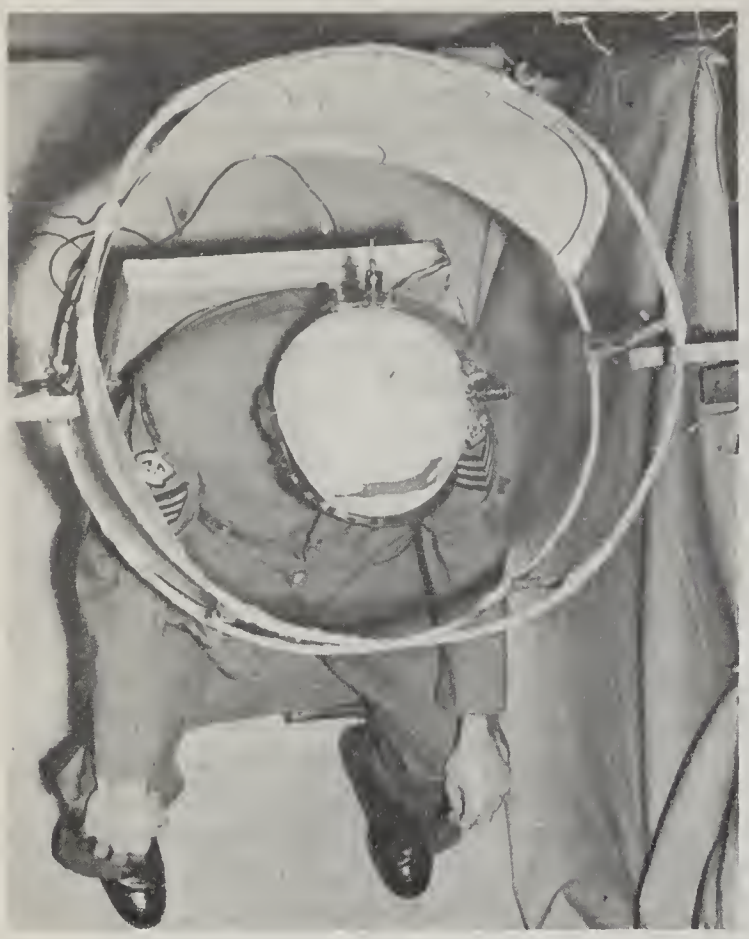

Figure 9 - View from above of electronic device for recording of head movements by surrounding subject's head with a magnetic field

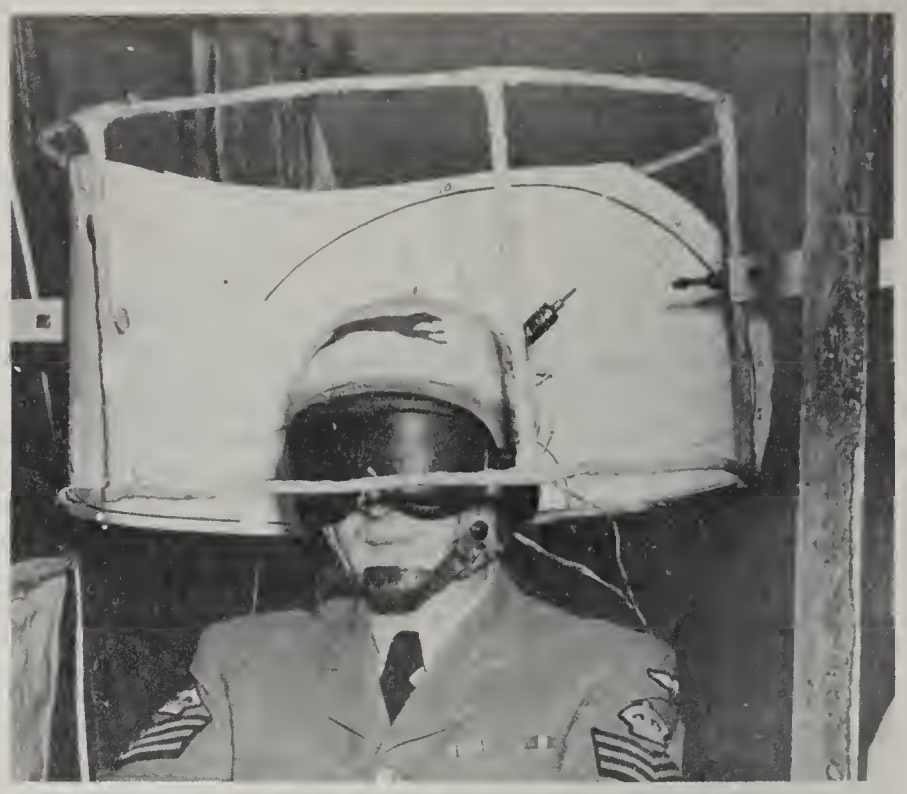

Figure 10 - Lateral view of electronic device for recording of head movements

made in a plane at right angles to a plane of passive rotation, the so-called Coriolis acceleration. This may take place for example during a spin if the pilot should meanwhile move his head up and down. When present, the Coriólis reaction usually produces marked vertigo and is especially dangerous in aviation for that reason."

As mentioned above, the gymometer enables a recording of the degree of angular momentum in each of the three orthogonal planes. A determination of such movements of the head may furnish a measurement of the intensity of stimulus (expressed as gyroscopic moments) required to produce motion sickness. At the moment, the movements of the head in the coronal and sagittal planes of the body are being

Figure 11 - Head support used in rear seat of Harvard trainer

determined both on the swing and in aircraft during aerobatics and in rough air. The apparatus being used is shown in Figures 9 and 10. The subject's head is surrounded by a homogenous electromagnetic field which enables the recording of head movements on a recording galvanometer induced by movement of the two coils attached to the helmet. The results obtained will be available in a separate report in the near future.

The results reported here also suggest the advisability of constructing head rests to be attached to the back of seats used in aircraft as a means of preventing airsickness among passengers and aircrew. Some preliminary tests have been made in this regard (Figure 11) with promising results and will be reported in the near future.

SUMMARY AND CONCLUSIONS

In studies involving the types of motion which induce sickness, it is necessary to measure the movements of the head as these show great individual variation even though the subjects be exposed to identical types of motion.

Individual susceptibility to swing sickness shows a significant correlation with the degree of head movement of the subject being swung. Swing sickness can be prevented by preventing this independent head movement, possibly the result of preventing any gyroscopic precession.

It appears that the results constitute a new method of attack on the cause and prevention of motion sickness and suggest subjects for further research.

* * *

REFERENCES

1. Armstrong, H. G., "Principles and Practice of Aviation Medicine," 1939

2. Brown, B. R., and Howlett, J. G., "Some Accelerometer Recordings in an Aircraft (Anson)," N.R.C. Canada, Report from No. 1 Air Observers School and No. 6 Medical Selection Board, April 1943

3. Howlett, J. G., et al., "The Effect of Position on the Incidence of Swing Sickness," N.R.C. Canada, Report for No. 6 Medical Selection Board, April 1945

4. Kelk, G. F., and Franks, W. R., "The Development of a Gymometer, an Instrument for Measuring Gyrational Moments (Precession)," abstracts of papers presented at the Aero Medical Association 19th Annual Convention, June 1948. Also in Proceedings Canadian Physiol. Sec., 12th Annual Meeting, October 1948

5. Manning, G. W., "Failure of a Vertical Accelerator to Produce Motion Sickness," N.R.C. Canada, Report No. 2649, December 1943

6. Morton, G., et al., "Mechanism of Motion Sickness," Arch. Neurology and Psychiatry, 57, 1, p. 58, January 1947

7. McEachern, D., Morton, G., and Lehman, R., "Seasickness and Other Forms of Motion Sickness," War Medicine, 2, 5, p. 410, May 1942

8. McIntyre, A. K., and Gardiner, I. D. R., "Correlation between Swing Sickness and Air Sickness," Royal Australian Air Force Report F. R. 67

9. McNally, W. J., and Stuart, G., "Physiology of the Labyrinth Reviewed in Relation to Seasickness and Other Forms of Motion Sickness," War Medicine, 2, 5, p. 683, September 1942

10. Rose, B., "Incidents of Nausea and Dizziness in 95 Subjects Following Runs in the Accelerator," N.R.C. Canada, Associate Committee on Aviation Medical Research, Report No. C-2882, August 1942

11. Spiegel, E. A., Henny, G. C., and Wycis, H. T., Am. J. Physiol. 142:589, 1944

12. Tyler, D. B., and Bard, P., "Motion Sickness," Physiol. Rev., 29, 4, p. 311, October 1949

13. Wendt, G. R., et al., "Studies of Motion Sickness," J. Psychol., 19, 1945

PSYCHOLOGICAL EFFECTS OF INCREASED POSITIVE RADIAL ACCELERATION*

Neil D. Warren
University of Southern California
Los Angeles, California

Neil D. Warren, Professor of Psychology, received his B.A. from the College of the Pacific. In 1934 he received his Ph.D. from the University of Southern California where he has been a member of the staff from 1932 to the present time.

INTRODUCTION

The program of psychological research on the human centrifuge at the University of Southern California was begun in 1947 under contract with the Office of Naval Research. The problems with which this research has been concerned involve psychological and psychophysiological changes during and following exposure to various amounts of positive *g*.

In general, two kinds of problems have been studied: (a) the effects upon certain primary abilities, such as spatial orientation, perceptual speed, etc., and (b) changes in some more complex functions whose applications to design and to personnel questions are more direct. In the latter group are studies of reaching speed and accuracy, and of maximum force which can be applied to airplane controls.

The factorial approach was adopted for two reasons. First, it provides an "economical" means of studying the behavior of the human organism, since a large part of this behavior can be described by a relatively small number of factors. The second reason for adopting the factorial viewpoint was that the abilities studied had been found valid for predicting success in pilot training by the Army Air Force during World War II. It was felt that these abilities were the ones most likely to be important in piloting modern high-speed aircraft.

Figure 1 - General view of centrifuge with subject in cab and observer in the podium

Figure 2 - Centrifuge cab and spatial orientation response mechanism, A - slide projector; B - anti-G suit air hose connection; C - spatial orientation response mechanism; D-lead wires to projector; E - screen

SPATIAL-ORIENTATION-ABILITY STUDY

A study of the effects of positive *g* on spatial orientation ability was undertaken first. A test was devised to measure this ability and apparatus was constructed suitable for presenting the test on the human centrifuge (Figures 1 and 2). The test items were adapted from the Spatial Orientation Test of

*ONR Project NR 143-098, Contract N6ori77, Task III

the Guilford-Zimmerman Aptitude Survey and were presented to the subject on an 8 x 10 inch screen by means of a slide projector. Each item represented a view seen from the cockpit of an airplane. These views showed a change in the airplane's heading when compared with a standard heading. The examinee's task was to duplicate that change with a response knob. The airplane might change its heading vertically or horizontally, and it might bank right or left.

In responding to an item, the subject moved a knob which recorded with a double-tipped stylus on a moving strip of stylograph paper. Completion of the response tripped the slide-changing mechanism and a new view appeared on the screen.

Twenty-one volunteer male college students were used as subjects and they received one 15-second test run at 1 *g*, 2 *g*, 3 *g*, 4 *g*, and 5 *g* each day for five daily sessions. In this study and in the studies which follow, the *g* levels were presented in counterbalanced order on different days to equate the influence of learning and of fatigue. Subjects were given one day of practice previous to testing and also received a short practice session at the beginning of each day.

F ratios were computed for differences between *g* levels for number attempted, number correct, and proportion correct. The F ratios for these were 0.610, 0.049, and 0.204 respectively. The F ratios necessary for a difference to be significant are 5.7 at the 5 percent level and 13.6 at the 1 percent level.

It is concluded that there is no impairment of spatial orientation ability, as measured, under conditions of increased *g* up to 5 *g* for durations of exposure up to fifteen seconds.

DISCRIMINATION-REACTION-TIME STUDY

The psychomotor test of discrimination reaction time was also found to be loaded on spatial-orientation ability by the Army Air Force. This ability was also studied using an apparatus patterned after the AAF Discrimination Reaction Time Test.

Twenty-three male college students served as subjects; and their task was to determine the direction that a red light lay from a green one on an exposure panel and then to move a toggle switch indicating that direction as quickly as possible. On each of four experimental days, subjects were tested twice at the normal resting condition (1 *g*) and twice each at conditions of 3 *g* and 5 *g*. The *g* conditions were randomized in abc abc order. Subjects' times for five responses during a 15-second interval were cumulated and tests made for differences in mean reaction time by use of the t ratio. Since each subject performed at each *g* level twice on each testing day (once during the first half of his trials and once during the second half of his trials), the two halves were treated separately.

Results indicate that for the first half of the first two experimental days, the mean reaction times of the subjects were very significantly slower at 3 *g* and at 5 *g* than at 1 *g*. However, the second-half trials for all the days and the first-half trials for the last two days were not significantly different from each other.

It is concluded that the ability of a subject to make efficient visual discriminatory reactions is impaired significantly under increased positive radial acceleration for the first few trials early in the history of exposure. This impairment is attributed to distraction, novelty, and apprehension associated with riding the centrifuge, rather than to any fundamental physiological embarrassment.

PERCEPTUAL-SPEED-ABILITY STUDY

Perceptual speed ability was studied using items like those in the perceptual speed test in the Guilford-Zimmerman Aptitude Survey. The test items consisted of five figures such as boats, clocks, shoes, radios, and so forth, arranged with one figure in the center and the other four above, below, to the left and to the right respectively. The subject's task was to indicate in which direction lay the figure which was exactly like the one in the center. The score was the number correctly responded to in each 15-second run at 1 *g*, 2.5 *g* and 4 *g*.

Fourteen volunteer subjects were given two experimental trials at each *g* level, on each of three different test days. As in the Discrimination Reaction Time experiment, the *g* orders for the first half and second half of the day's trials were counterbalanced separately.

Performance at all *g* levels was significantly better during the last half of the day's trials than during the first half, so the results of the two halves were treated separately.

The only significant differences found were between 1 *g* and 4 *g* and 2.5 *g* and 4 *g* for the first half of the day's trials. Subjects made significantly fewer correct responses at 4 *g* than at 1 or 2.5 *g* during this first half. Since this decrement at 4 *g* was found only in the first half of the day's trials, and since performance at all *g* levels was significantly higher for the second half, the early 4 *g* decrement is attributed to the distractions associated with the first few rides of the day rather than to any fundamental physiological changes.

From the results of these three studies it is concluded that visual discriminatory processes and certain basic mental abilities are not affected by increased positive radial accelerative forces up to a level of 5 *g* as long as vision is maintained.

REACHING-SPEED-AND-ACCURACY STUDY

Among the studies not based on the factor approach, the investigations of changes in speed and accuracy of movement seems most pertinent to this discussion. The first of these involved simple movements of ballistic character. The subjects were required to thrust at targets located above, below, to the right, and to the left of the shoulder (Figure 3). The study is being continued with different kinds of movements. For example, the subjects are required to operate switches of various types and in various positions.

Figure 3 - Subject striking target in the reaching-speed-and-accuracy study

In the first study* the subject was instructed to move his hand from the starting point, a switch mounted 5 inches in front of and at the level of the shoulder, to the target. The target was a five-inch square of polar-coordinate graph paper, located 19-1/2 inches from the starting point and at an angle of 45° from the midline. The subject attempted to strike the center of the target with the tip of the finger. A metal stylus worn on the finger marked the target for measurement of the accuracy of the movement. Reaction time was determined by measuring the interval between a starting buzzer and the beginning of the movement; movement time was determined by recording how long it took to reach the target. Target position and *g* levels (1 *g*, 3 *g*, and 5 *g*) were systematically varied to avoid practice or fatigue effects.

The movements at the increased *g* levels, for all target positions, were less accurate and slower than at 1 *g*.

Reaction time was significantly longer at 3 *g* and 5 *g* but did not vary significantly from one target position to another.

Movement times for targets above and to the left were most affected. For example, the movement to the upper target required 1.35 seconds at 1 *g* and 2.20 seconds at 5 *g*. This increase is probably due to the greater effective weight of the arm at the higher levels. There was no parallel decrease in movement time to the lower target, however.

Accuracy of movement decreased significantly for all target positions with increased *g*. This was interpreted to indicate an inadequacy of kinaesthetic cues for the movement. The increased effective weight of the arm required learning a new pattern of kinaesthetic cues for a movement of the same direction and extent as one made at 1 *g*.

---

*This study was conducted by Dr. Albert A. Canfield, now, Assistant Professor of Psychology at Northwestern University.

Two types of errors were observed. One was a tendency to fall below the target at higher g levels. This was apparently due to an underestimation of the effect of increased weight of the arm. The other has been called the negative inertia-error and appears to be the result of failure to thrust the arm far enough in the reaching movements. As might be predicted, these errors produce an accumulation of strikes in the lower and inner quadrants for the right and left targets, and for the lower half of the target in the upper position. With the target in the lower position the two tendencies act in opposite directions. The negative inertia-error appeared to prevail over the error of underestimation. As a result there is greater accuracy for this target with some accumulation of strikes on the upper half. The size of the errors and time of movements were smaller for targets in the lower and right positions, suggesting that these positions offer greater advantages for location of controls that might have to be located quickly and accurately under conditions of increased radial acceleration.

Continuing studies of this problem indicate that the type of movement required of the subject has a relationship to the speed and accuracy of the movement which may suggest the most advantageous location, not only of emergency controls, but of particular kinds of knobs, switches, etc.

* * *

THE LAG EFFECT ASSOCIATED WITH STIMULATION OF THE SEMICIRCULAR CANALS AS INDICATED BY THE OCULOGYRAL ILLUSIÓN*

W. Brant Clark, San Jose State College, San Jose, California
and
Capt. Ashton Graybiel, MC, USN
U. S. Naval School of Aviation Medicine
Pensacola, Florida

INTRODUCTION

Previous investigations have shown that the oculogyral illusion is a good indicator of stimulation of the semicircular canals in man (1,4). If a person in a dark room is subjected to angular acceleration in the horizontal plane while he observes a luminous object which rotates with him, the object will appear to move in the direction of turn (first effect). In time, the object will appear to come to rest if a constant rate of rotation is maintained, and subsequently, the object may appear to move in the opposite direction (second effect).

W. Brant Clark received his B.A. from the University of California, then taught at the University of Southern California while obtaining his M.A. and Ph.D. degrees. In 1936 Dr. Clark became affiliated with San Jose State College where he is now Professor of Psychology. From 1943 to 1946 he served with the Navy at the Naval School of Aviation Medicine, Pensacola.

It has been known at least since Mach's monograph in 1875 that accelerative aftereffects may weaken decelerative nystagmus (8). In most studies no systematic attempt has been made to study these lag effects of accelerative stimuli on subsequent accelerative phenomena. However, an increase in nystagmus time with increasing temporal interval between stimuli has been reported in both humans and animals (3,5,9,10,11). This has been reported in the case of the oculogyral illusion itself (1). In spite of the fact that several studies have considered this lag effect, there is no agreement on the precise nature of the mechanism involved, and little data on the degree of interference are available (7,12).

The purpose of this experiment was to measure the extent to which the lag effects of previous angular acceleration inhibit the oculogyral illusion produced by a succeeding angular acceleration of opposite sign. The results are of interest in relation to the underlying psychophysiological mechanism of the oculogyral illusion, but they also have implications regarding the reduction of this illusion in flight in an aircraft.

APPARATUS AND PROCEDURE

The observations in this experiment were made in an airconditioned, dark room (4) where the subjects were exposed to a series of angular accelerations followed by decelerations at different time intervals. The rotation apparatus consisted of a Link trainer modified to rotate only on a vertical axis. The trainer was rotated only in a clockwise direction (to the subject's right) and was controlled by the experimenter in an adjacent room. Communication between the subject and the experimenter was possible by means of a standard communication system. The target box, used as a fixation object, was mounted on a heavy strut which placed the box two meters directly in front of the subject's eyes. The box, which was 8 x 8 x 14.5 cm., contained a light source and was opaque except where it was pierced along its edges by 3-mm holes placed 10 mm apart. It was tilted so that the subject could see three

*BuMed Project NM 001-059.01.25

sides, the light intensity being regulated by the subject so that the edges of the box were clearly visible in an otherwise dark room.

Six sophisticated, healthy subjects were used. They sat in the Link trainer with eyes closed and head tilted forward approximately 25 degrees. Head movements were minimized by means of a bite-board mounted on a metal stanchion at the center of rotation of the trainer. The subject, rotated to the right at a given speed, opened his eyes at the command of the experimenter at the onset of deceleration. He reported on the apparent motion of the target (oculogyral illusion) until all motion had ceased. The subjects' reports of the duration of the various phases of the apparent motion of the target were timed by the experimenter to the nearest second, beginning at the time the brake was applied. Between trials the room lights were turned on for 15 to 30 seconds and enough time was allowed to have a minimum of two minutes between trials.

The accelerative stimuli were presented by setting the Link trainer so that it would accelerate to 5, 10, or 15 rpm as a maximum rate of rotation; the mean acceleration times were 2.3, 4.3 and 6.4 seconds, respectively. These rates of rotation were held for prearranged periods of time and then the trainer was quickly brought to a stop by means of a friction brake. The deceleration time was of the order of 0.5 second. Six intervals of constant rotation were used between the time the desired velocity was reached and the point of deceleration. These times were: 0, 10, 20, 30, and 60 seconds. The order of presentation of the stimulus situations was arranged in a counterbalanced order, each subject being exposed to three trials for each experimental condition, making a total of 45 trials for the experiment. The trials were run in nine series of five each with a minimum of 30 minutes between series. The data were collected over a period of two weeks.

RESULTS

The analysis of the data has been made in terms of the postrotary oculogyral illusion, first effect (apparent motion to the left), the second effect (apparent motion to the right) and the total duration of the

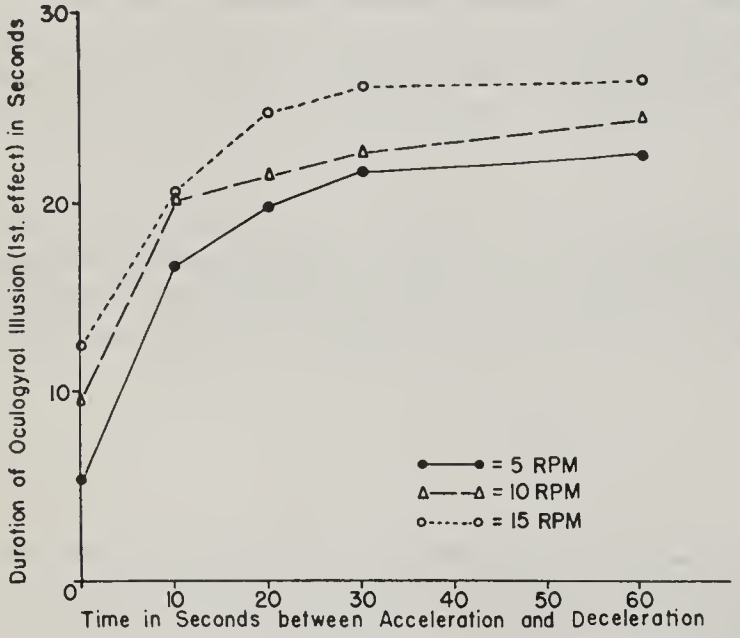

Figure 1 - Duration of the decelerative oculogyral illusion (first effect) following five time intervals between acceleration and deceleration. Each point is the mean of three observations for each of six subjects

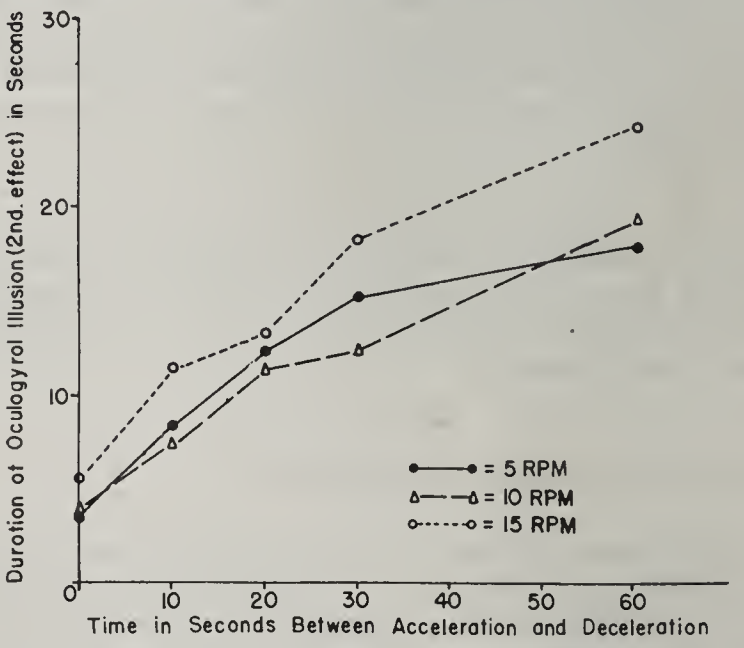

Figure 2 - Duration of the decelerative oculogyral illusion (second effect) following five time intervals between acceleration and deceleration. Each point is the mean of three observations for each of six subjects

oculogyral illusion which is merely the sum of the first and second effects. Clearly defined lag effects were found in each case (Figures 1, 2, and 3). The duration of the illusion was not only decreased but it was less clearly defined, and the subjects frequently reported some difficulty in making their judgments.

As the interval between acceleration and deceleration increased, the oculogyral illusion increased at first sharply and then more gradually giving a negatively accelerated curve (Figure 1). The average increase in the duration of the illusion from zero delay to sixty seconds of constant rotation was between two and four times. The nature of the curve indicates that the increase beyond 60 seconds would be slight.

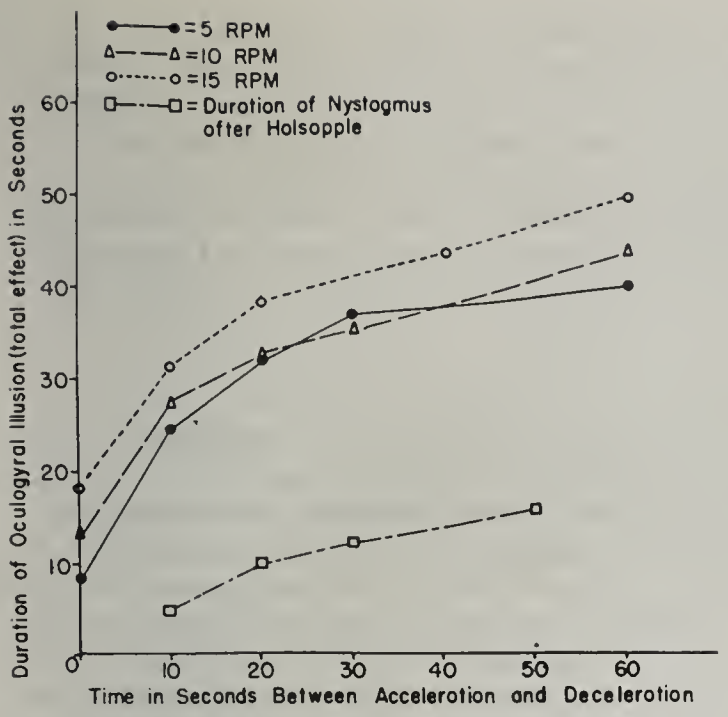

Figure 3 - Duration of the decelerative oculogyral illusion (total effect) following five time intervals between acceleration and deceleration. Each point is the mean of three observations for each of six subjects.

This is supported by additional evidence found in another study (1) and by additional data below. It is of interest to note that there is only a small displacement between the three curves throughout in spite of very marked differences in the rates of rotation. These data show that the lag effects of an accelerative stimulus are strong for approximately 10 seconds and practically disappear after 30 seconds insofar as the oculogyral illusion (first effect) is concerned. Very short intervals between stimuli resulted in interference which amounted to complete elimination of the post-rotatory effects on some trials.

The second effect (i. e., apparent motion to the right following the first effect) was reported by five out of the six subjects. Its duration was also sharply reduced when deceleration followed acceleration by a short interval (Figure 2). The duration of the second effect was approximately five times greater following 60 seconds of constant rotation than it was when deceleration followed acceleration immediately. The lag effect shows almost a straight line relationship between the delay and duration of the second effect up to 30 seconds and then the curve becomes negatively accelerated. It is clear that the increase in the second effect would be expected to continue beyond the sixty second interval used in this experiment. Again, the differences between the three rates of rotation were found to be small. The total duration of the oculogyral illusion showed the same general pattern as the second effect (Figure 3).

One subject was also studied using a modified procedure. Fifty trials were run at 15 rpm following the same procedure used with the other subjects except that he was rotated two minutes at a constant velocity before deceleration. Fifty additional trials were run in the same fashion except that the subject opened his eyes as his feelings of rotation disappeared and gave the signal to stop as soon as the accelerative oculogyral illusion (second effect) appeared at full strength. The mean time to the stop signal came at 49.5 seconds (σ = 4.4 sec). Thus, the deceleration was applied while there was a clear aftereffect of motion in the same direction as the oculogyral illusion (first effect) following rotation. Considering the data above one might expect that the various parts of oculogyral illusion would be somewhat less at this point for two reasons: First, there was less time between the accelerative and decelerative stimuli, and second, the eyes were opened for a longer period. The results summarized in Table 1 show, however, that the situation is complex. The subject reported a longer first effect (3.4 sec) when he signalled the stop than when the rotation lasted two minutes. On the other hand, the mean

TABLE 1

Mean Duration of the Post-Rotary Oculogyral Illusion for One Subject in Seconds. Each Figure is the Mean of 50 Observations.

	Mean	σ	Critical Ratio
First effect			
2 min. rotation	26.5	2.6	5.7
Signal to stop	29.9	2.7	
Second effect			
2 min. rotation	39.8	7.8	14.7
Signal to stop	20.5	11.5	
Total effect			
2 min. rotation	66.8	8.4	7.6
Signal to stop	50.0	12.5	

second effect was 19.3 seconds shorter when the trainer was stopped at the subject's signal. As a result the total effect was also significantly shorter for the shorter rotation. These results are somewhat marred by the fact that in the final 25 trials the subject reported a significantly shorter second effect for the shorter rotation. A similar effect was found for the two minute trials, but it was not statistically significant. A comparison of the first effects for the two conditions showed a mean difference in each case of only 0.1 second for the first and second 25 trials. These results tend to show that other factors than time alone may affect the duration of various parts of the post-rotary aftereffects.

DISCUSSION

During normal everyday activities, rotary movements of the body as a whole, or of the head itself, involve accelerations which may be fairly large but which are usually followed within an extremely short period by decelerations (7, 9). Therefore, as the data described above show, during normal activities which do not ordinarily involve prolonged rotation, the lag effects of angular acceleration in one direction can be expected to damp or even completely cancel out the effects of acceleration in the opposite direction. The net result is that there will be little or no perceptible aftereffect even though the accelerations involved are relatively large and the conditions are favorable for the observation of the phenomenon. However, the situation is quite different when an individual rotates at a constant velocity for 10 seconds or more and then observes an isolated target in the dark when the rotation is stopped. Under these conditions the lag effect is small, and if other conditions are favorable, the illusory motion will be perceived. Therefore, it can be expected that flyers, for example, will be susceptible to illusory aftereffects of rotation upon suddenly recovering from a maneuver in which the plane was rotated about one of its axes for a prolonged interval. Similarly, a reduction in these effects can be expected where it is possible to avoid rapid recovery from prolonged turns and when rotations are short lived.

It is worthy of note that the lag effects found in this study show the same general pattern as those reported by Holsopple for nystagmus in a human subject (5, p.93), although, as would be expected, the duration of the nystagmus is much shorter (Figure 3). Furthermore, it can be seen from his data that the lag effect continues beyond the duration of the experiment which was 50 seconds. However, the two studies are not directly comparable since the precise nature of the accelerative stimuli is not known for either, and other crucial variables are not the same.

Even more striking similarity is to be found in comparing the data on the lag effect with the apparent displacement of a sound following angular deceleration (audiogyral illusion). The temporal changes are closely similar in spite of the fact that the lag effect is associated directly with vestibular nystagmus while the audiogyral illusion is undoubtedly due to much more complex effects (2). It should also be pointed out that the data show the same general pattern as the scheme of the cupula deflection presented by Lowenstein and Sand for the ray (Figure 10 of reference 7).

These results also have some implications with regard to the underlying physiological mechanism of the semicircular canals. The lag effect in this study decreased as the time between acceleration and deceleration increased. It should also be noted that the duration of the lag effect very roughly approximates the duration of the oculogyral illusion (first effect). This could have been predicted on the basis of the Mach-Breuer theory of the mechanism of the semicircular canals. It also is consistent with the work of Lowenstein and Sand which indicates that in the ray the deflection of the cupula lasts some 20 to 30 seconds and that this cupular deflection and the nervous discharge are proportionately less when deceleration follows acceleration within 20 seconds (7). The results of this experiment, therefore, suggest a relationship between the displacement of the cupula and the duration of the lag effect and the oculogyral illusion.

The data on the second effect are much less clearly explicable since it probably persists well beyond the period of measurable nervous discharge and apparent distortion of the cupula. The lag effect decreases as in the case of the first effect but it continues beyond the 60-second interval between stimuli. This would support the notion that the mechanism producing the second effect may be different from that producing the first effect. Here, the possibility of central facilitation must be considered.

REFERENCES

1. Clark, B., and MacCorquodale, K., "The Effects of Repeated Rotary Acceleration on the Oculogyral Illusion," J. Exp. Psychol. 39: 219-227, 1949

2. Clark, B., and Graybiel, A., "The Effect of Angular Acceleration on Sound Localization: The Audiogyral Illusion," J. Psychol. 28: 235-244, 1949

3. Dunlap, K., and Dorcus, R. M., "The Effect of Rate of Retardation on Post-Rotation Nystagmus," J. Comp. Psychol. 6: 329-335, 1926

4. Graybiel, A., and Hupp, D. I., "The Oculogyral Illusion," J. Aviat. Med. 17: 3-27, 1946

5. Holsopple, J. Q., "Some Effects of Duration and Direction of Rotation on Post-Rotation Nystagmus," J. Comp. Psychol. 3: 85-100, 1923

6. Lorente de No, R., "Researches on Labyrinth Reflexes," Trans. Amer. Otol. Soc. 22: 287-303, 1932

7. Lowenstein, O., and Sand, A., "The Mechanism of the Semicircular Canal," Proc. Royal Soc. Med. 129, Series B, No. 855, 1940

8. Mach, E., "Grundlinien der Lehre von der Beusgungemphendungen" (Principles of the Theory of Motion Sensations), Leipzig: William Engelmann, 1875

9. Mowrer, O. H., "Concerning the Normal Functioning of the Vestibular Apparatus," Annals. Otol., Rhino, and Laryng. 41: 412-421, 1932

10. Mowrer, O. H., "Some Neglected Factors Which Influence the Duration of Post-Rotational Nystagmus," Acta Oto-Laryng. 22: 1-23, 1935

11. Pilz, G. F., "On the Relation of the After-Nystagmus to Rotation Nystagmus," Amer. J. Physiol. 77: 428-442, 1926

12. Sand, A., "The Mechanism of the Acusto-Lateral Sense Organs in Fishes, with Special Reference to Problems in the Physiology of the Semicircular Canals," Proc. Royal Soc. Med. 33: 741-750, 1940

THE EFFECT OF A CHANGE IN DIRECTION OF RESULTANT FORCE ON SOUND LOCALIZATION: THE AUDIOGRAVIC ILLUSION*

Capt. Ashton Graybiel, MC, USN and Jorma I. Niven
U. S. Naval School of Aviation Medicine
Pensacola, Florida

INTRODUCTION

If a person, who is in a fixed position on a human centrifuge, is subjected to centripetal force, he will tend to reorient himself in conformity with the resultant of this force and the force of gravity. Thus, he will have the illusion that he has shifted his position with reference to the vertical, and objects in the visual field will appear to have assumed new positions in space (1). Whether, under these circumstances, a person also tends to relocalize a source of sound forms the subject matter of this report. Insofar as we are aware, there have been no previous investigations of this specific problem. However, it is closely related to other illusory phenomena which are based on a similar psychophysiological mechanism (2).

Jorma I. Niven attended Clark University where he received his B.A., M.A., and Ph.D. degrees. In 1942 he became an assistant in the Harvard University School of Business Administration. Since 1948 he has been a research psychologist at the Naval School of Aviation Medicine, Pensacola.

APPARATUS AND PROCEDURE

The experimental design required that a person be subjected to a change in direction of resultant force, which was greater than the subject's error in localizing a source of sound. The human centrifuge imposed a limitation in that the change in direction of resultant force was confined to one plane. This corresponded to the saggital or frontal plane of a subject seated upright on the centrifuge, facing, respectively, toward or at a right angle to the center of rotation. The subject imposed a limitation in that the ability to localize a source of sound in either of these planes is extremely poor. These difficulties were resolved by positioning the subject's head so that a change in direction of resultant force occurred in a horizontal plane with reference to the ears. Thus the subject could be afforded the most favorable circumstance for right-left sound localization.

The centrifuge was of the inertia-wheel type which has been described in a previous communication (3). A small, sound-insulated chamber was mounted on one arm of the centrifuge (Figure 1). It was constructed of aluminum alloy and formed a sphere except at the base where a segment, comprising 90 degrees of arc, was replaced by a cylinder 3 feet in diameter and 9 inches high. The chamber was lined with three layers of soundproofing material, the innermost consisting of corrugated wool felt. The floor was covered with a felt carpet.

Matched dynamic earphones (ANB-H-1a) were placed at 5-degree intervals of arc in a circle which divided the sphere into right and left halves (Figure 2). This circle was complete except for the segment of 90 degrees at the base. The plane of this circle was the same as that in which the change in direction of resultant force occurred during centrifugation.

---

*BuMed Project NM 001-059.01.23

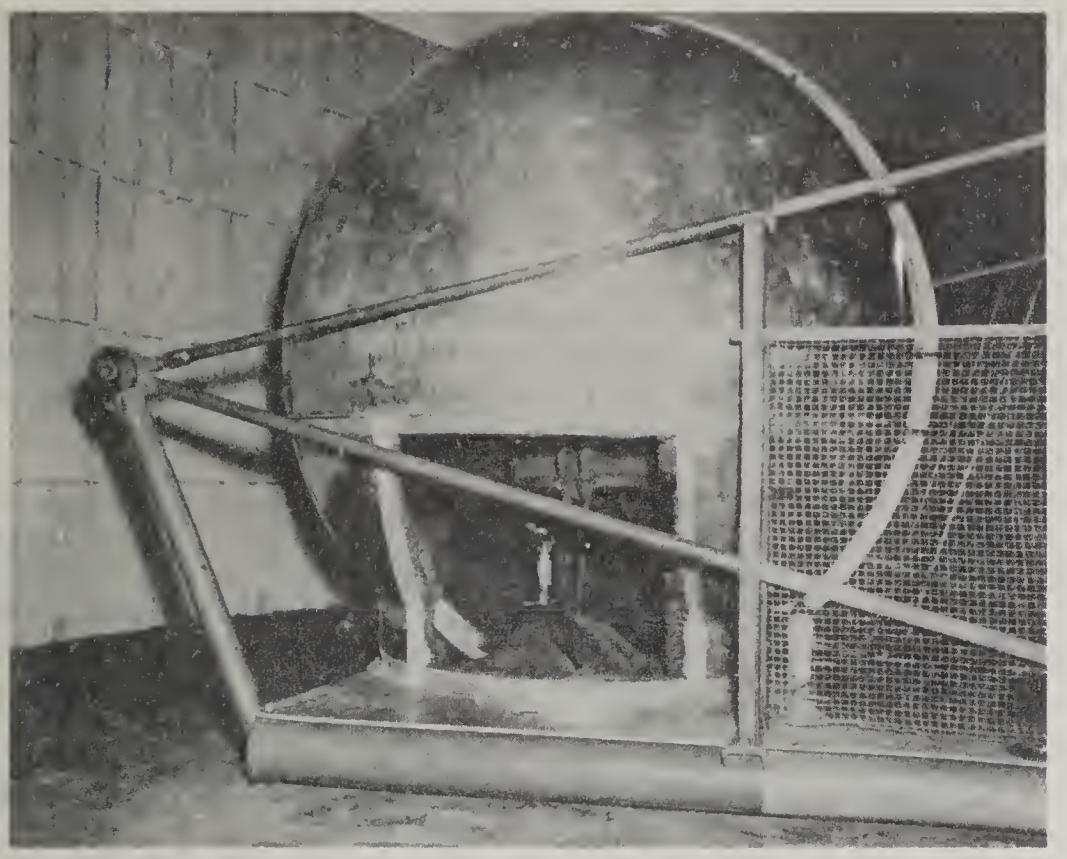

Figure 1 - The test chamber as mounted on the centrifuge with entry hatch removed

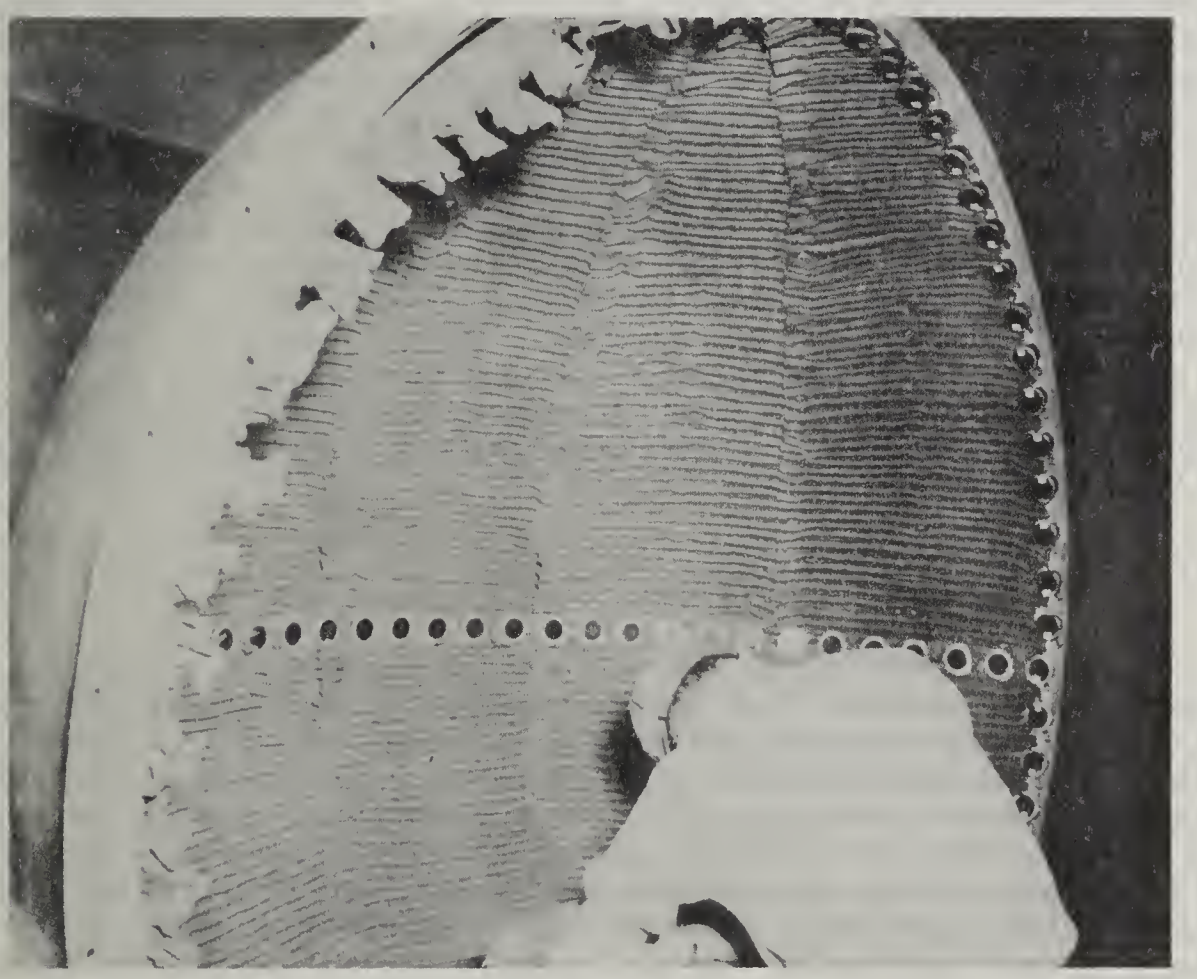

Figure 2 - The test chamber dismantled to show placement of earphones and experimental position of subject

Each earphone was connected with a Maico audiometer on a separate circuit connected to a central switchboard. Insertion of a common jack completed the circuit at that point and started a small motor. A cam mounted on the motor shaft activated a switch which completed the circuit between earphone and audiometer. The cam was so cut that the stimulus tone of 1024 cps was limited to 0.1 second duration. After presentation of a stimulus tone the experimenter pulled the jack to avoid repetition of the stimulus.

The experimenter and control panel were located at the central column of the centrifuge. The experimenter maintained a positive check on the presentation of the stimulus by means of a signal light which flashed during the period when the circuit was complete. A one-way communication system allowed the subject to speak to the experimenter; the latter could signal the subject by means of flashing lights to indicate the beginning and ending of an experimental session.

Within the chamber was a seat so designed that the subject could sit with head inclined 90 degrees toward the shoulder. The position of the head was maintained by means of an adjustable metal helmet lined with foam rubber; a padded armrest beneath the headpiece provided an additional means of support. At the highest level of acceleration the subject required the use of a hand-hold mounted on the chamber wall. The center of the subject's head was in the center of the sphere which was 16.8 feet from the center of rotation. A line passing through the subject's ears coincided with the vertical axis of the sphere.

Four healthy men with normal hearing served as subjects. Each was thoroughly familiar with the experimental procedure and three of the four had had previous experience with disorientation effects due to acceleration. Two seating positions were used; in one the subject faced toward and in the other he faced away from the center of rotation. Each subject was tested when the centrifuge was stationary and at each of three levels of acceleration producing an angle ($\emptyset$) of 11.4, 19.7, and 29.2 degrees between the resultant force and the vertical. Under each of these four conditions the subject was required to estimate the location of one of four different test positions. The first or zero position was directly before him. The other positions were 15 degrees below and 15 and 30 degrees above the zero point.

In the experimental trials the three variables concerned - seat position, magnitude of acceleration, and tone position - were randomized and counterbalanced. A modified method of limits was used for determining the subject's estimation of the several test positions. First, the subject was informed which of the four positions he was expected to localize. He was then presented with a succession of stimulus tones beginning well away from this point and gradually sweeping toward it. The subjects were instructed to respond with "no" to all incorrect stimuli, and "yes" when they judged that the direction of the stimulus tone coincided with that of the test position they were to localize. Because of the ease of confusion, they were cautioned to refer the stimuli at all times to what seemed to be the true horizon. A common source of difficulty in disorientation experiments is that different subjects or even the same subject at different times may shift his reference point from what seems to be the true horizon to what he "knows" it to be after compensating for the effects of acceleration. All judgments were made with the eyes open but in darkness to rule out the influence of visual cues. Two judgments were made, one in which the approach was made from below and one from above the test position. Two judgments for each of the four positions constituted an experimental trial. Eight such trials comprising all combinations of seating positions and levels of acceleration were given each subject. A rest period of at least 30 minutes was allowed between trials.

RESULTS

The mean judgments of apparent displacement of a sound source from its true position under conditions of acceleration are presented in Table 1. Under stationary conditions, the mean absolute error in localization of the four test positions was 1.5 degrees; the range was -1.9 to +2.2 degrees. Under conditions of acceleration and when the subject faced toward the center of rotation he localized a source of sound as coming from below its true position. This apparent displacement increased uniformly with the increase in the angle $\emptyset$, and on the average it amounted to approximately 70 percent of this angle. When the subject faced away from the center of rotation he consistently localized the source of sound above its true position. The displacement was of the same magnitude but opposite in sign as when the subject faced toward the center of rotation. The arithmetical sum of the errors in localization represents the maximum degree of error at a given level of acceleration when the subject reversed his position with respect to the direction of resultant force.

TABLE 1

Localization of the Four Test Positions at Different Levels of Acceleration in the Two Seating Positions. (Each Datum Represents the Mean of Two Measurements.)

True position (deg)	Subject	Resultant angle Ø* (deg) -29.2	-19.7	-11.4	0	+11.4	+19.7	+29.2
		Estimated position (deg)						
+30	AG	+ 7.5	+10.0	+17.5	+28.8	+30.0	+42.5	+55.0
	JN	+15.0	+ 7.5	+17.5	+28.8	+45.0	+42.5	+60.0
	BM	-25.0	+25.0	+27.5	+32.5	+45.0	+62.5	+42.5
	FG	+ 5.0	+ 5.0	+20.0	+22.5	+32.5	+37.5	+55.0
	Mean	+ 0.6	+11.9	+20.6	+28.1	+38.1	+46.2	+53.1
+15	AG	0.0	+ 5.0	+10.0	+13.8	+30.0	+27.5	+47.5
	JN	- 7.5	- 2.5	+17.5	+20.0	+37.5	+35.0	+35.0
	BM	+ 2.5	+ 7.5	+17.5	+13.8	+22.5	+45.0	+22.5
	FG	0.0	- 7.5	+ 5.0	+12.5	+17.5	+15.0	+32.5
	Mean	- 1.	+ 0.6	+12.5	+15.0	+26.9	+30.6	+34.4
0	AG	-20.0	- 7.5	-15.0	+ 2.5	+ 7.5	+10.0	+37.5
	JN	-20.0	-25.0	-17.5	0	+15.0	+17.5	+20.0
	BM	- 5.0	- 2.5	+ 5.0	+ 5.0	+ 7.5	+45.0	+10.0
	FG	-20.0	-17.5	- 2.5	0	+ 2.5	+22.5	+20.0
	Mean	-16.2	-13.1	- 7.5	+ 1.9	+ 8.1	+23.8	+21.9
-15	AG	-35.0	-20.0	-17.5	-11.3	-12.5	0.0	+ 7.5
	JN	-40.0	-40.0	-35.0	-12.5	-12.5	-10.0	- 2.5
	BM	-22.5	-22.5	-10.0	-15.0	-10.0	+ 7.5	- 2.5
	FG	-30.0	-22.5	-17.5	-12.5	0.0	+ 5.0	+10.0
	Mean	-31.9	-26.2	-20.0	-12.8	- 8.8	+ 0.6	+ 3.1

*Minus values relate to data obtained when subject faced the center of rotation and positive values when subject faced away from the center of rotation. Data from both positions combined when Ø was zero degrees.

Average measurements are plotted in Figure 3 in which the abscissa represents the true position, and the ordinate, the estimated position. The linearity of the function at each level of resultant force is apparent. The straight lines fitted to each set of data were derived by the least-squares method. It is especially interesting to note the systematic displacement as a function of direction and magnitude of acceleration. Although each point represents a mean of only 8 readings, there is only one reversal which occurs between the two highest values for Ø at the 0-degree test position. This regularity is the more remarkable because of the distraction introduced by the physical effort required to maintain body position particularly at the highest level of acceleration.

The straight-line curves represent a best-fit function; goodness of fit must also be considered. Accordingly, r^2 was computed for each condition. The proportion of the variance of the subjective

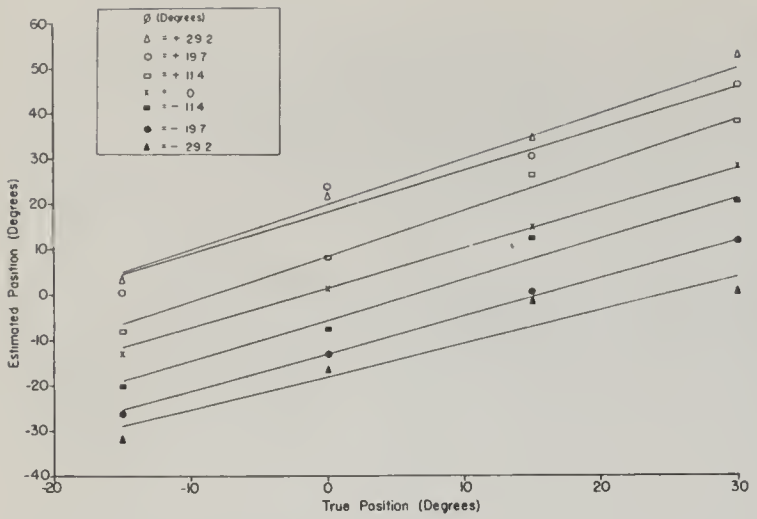

Figure 3 - The relationship of estimated position of a test tone, at various levels of acceleration, as a function of position with respect to the "horizon." Each datum represents the mean of eight measurements.

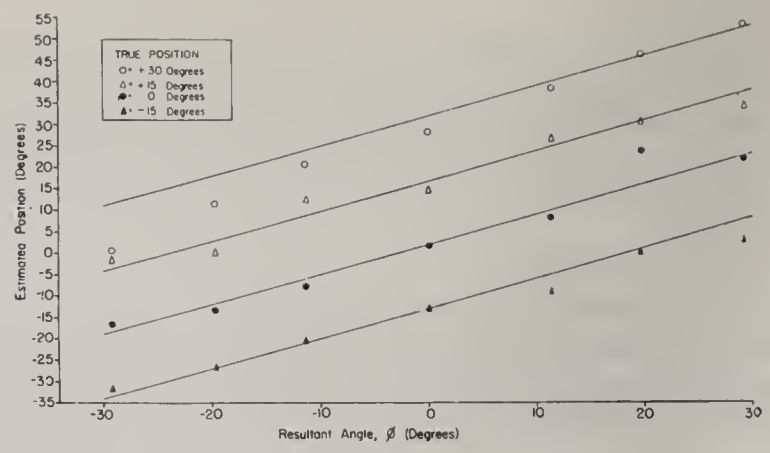

Figure 4 - The relationship of estimated position of a test tone, at various positions with respect to the "horizon," as a function of the resultant angle Ø. Each datum is the mean of eight measurements.

estimate of the true position, which is due to changes in the test position itself, is thus determined. These values are given in the last column of Table 2. It may be inferred from these values that the goodness of fit is adequate.

Table 2 also gives the slope and intercept characteristics of each of the family of curves in Figure 3. The intercept value k in the straight line equation $y = mx + k$ may in this case be considered to represent the displacement of the curve due to resultant force. A plot of k, which—as the apparent displacement of the sound source—will be designated in the future by $Ø_a$, against the calculated resultant angle Ø also gives a straight line function (Figure 4). The r^2 value for this relationship was 0.98, indicating an exceptionally good fit. Only about 2 percent of the variance in $Ø_a$ was not attributable to variation in the resultant angle Ø.

TABLE 2

Evaluation of Best-Fit Curves for Estimation of Angular Direction Data of Table 1

Resultant angle (deg)	Slope (m)	Y-intercept (k)	Percentage of Y-variance attributable to X (100 r^2)
+29.2	+1.0	+20	94
+19.7	+0.92	+18	92
+11.4	+1.0	+ 8.7	94
0	+0.87	+ 1.5	96
-11.4	+0.91	- 5.4	94
-19.7	+0.82	-13	96
-29.2	+0.75	-18	88

An analysis was also made with respect to the variations in the slopes of the curves in Figure 3. A plot of the slope m against the angle Ø did not appear to give a good linear function. The obtained r^2 of 0.01 bore out the conclusions arrived at from an inspection of the data. Only 1 percent of the variance in slope was attributable to variance in Ø.

The data were also examined to determine if the accelerative forces influenced the apparent displacement of the sound source similarly at all test positions. The estimated positions of the sound source were plotted against resultant angle Ø, giving four functions for the four test positions (Figure 4). Note that at the 0-degree test position, the data are fitted well by the curve $Ø_a = m Ø + c$ derived from Figure 3 above. This same curve when arbitrarily displaced by 15 and 30 degrees upwards and 15 degrees downwards should give an equally good fit at those test positions, if the test position itself does not have any influence on localization under the conditions of the present experiment. It can be seen from Figure 4 that expectation is adequately met at the +15- and -15-degree test positions. At the +30-degree position, the subject's estimation of the apparent displacement while facing toward the center was less than that which was anticipated.

This departure does not indicate a true change of function when the data are considered in terms of average deviations. The estimated position minus the true position gives a direct measure of the

displacement of the sound source due to accelerative forces, i.e., of ϕ_a. A plot of ϕ_a against caluclated ϕ should give a nearly superimposed series of points such as would be obtained by adding or subtracting constants equal to the true position to the curves of Figure 3. Such data are graphed in Figure 5 and fitted with a best-fit line by the least-squares method. Again it may be seen that the displacements obtained when the test position is 30 degrees above the horizon and the subjects are facing toward the center of rotation seem to deviate from the general trend.

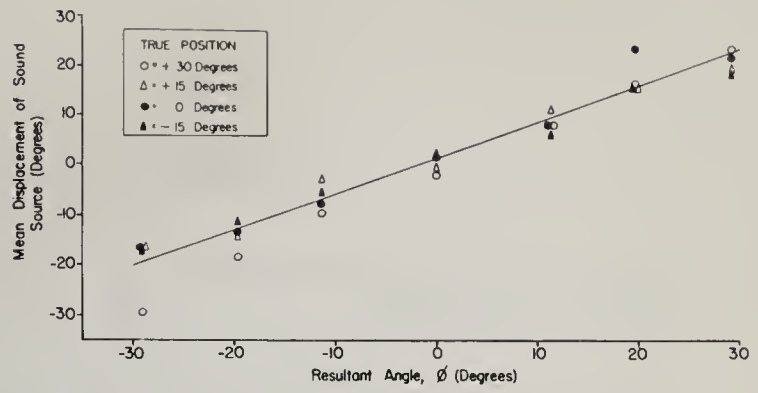

Figure 5 - Mean displacement of a sound source, at various positions with respect to the "horizon," as a function of resultant angle. Each datum represents the mean of eight readings.

The likelihood that the deviations of the experimental means from the best-fit line were not due to chance was then subjected to a statistical test. An F of 0.83 with 5 and 18 df was obtained. This value was far below the 2.77 required to show a significant difference at the 5 percent level. Hence, the variation of the experimental data from the best-fit curve can be attributed to chance.

DISCUSSION

These data have shown that, under the experimental conditions described, the localization of a source of sound in terms of a vertical-horizontal frame of reference is influenced by the change in direction of resultant force. This phenomenon has been termed the audiogravic illusion. The apparent displacement is quite uniform within the range tested. A linear relationship was found to exist between the amount of apparent displacement and the angle ϕ; the former can be described by the empirical expression $\phi_a = 0.69\,\phi + 1.7$ and amounts to approximately 70 percent of the angle ϕ.

The audiogravic illusion is readily explained as follows. Under static conditions and in the absence of visual cues the subject judges the position of a stimulus tone with reference to a point on the horizon directly before him. Now the estimation of the horizontal and vertical axes depends, fundamentally, on cues which orient a person to the direction of gravity. These arise by virtue of direct contact with the supporting structures and include stimuli from sensory elements in the nonacoustic labyrinth, muscles, tendons, joints, skin, and elsewhere.

Under conditions of acceleration these same sensory organs orient a person in the direction of resultant force. Inasmuch as the subject in our experiment was not free to change position, there was a change in angle between the body axis and resultant force; accordingly he had the illusion of feeling that he was tilted. The egocentric localization of the vertical and horizontal axes now accords with the direction of resultant force and not the true vertical. Hence the localization of a point source of sound within this frame of reference would cause the subject to be in error with respect to the true position of the stimulus.

During a course of preliminary training in the localization of test tones, it had been observed that the subjects tended to underestimate the angular displacement of a tone from the horizon. It was anticipated, therefore, that an underestimation of displacement due to changes in the resultant angle would occur in the present experiment. It was found that the subject's reorientation of the sound source fell short by approximately 30 percent. If this underestimation is taken into consideration, the data indicate that error in auditory localization under the conditions of this experiment approximates the resultant angle θ, subject to a constant correction factor reflecting an individual's ability to localize a test tone under static conditions.

ACKNOWLEDGMENT

The authors are indebted to Mr. F. E. Guedry, Jr., Tulane University, and B. H. Monaghan, HM2, USN for serving as subjects, and to the staff of the Acceleration Unit for their assistance.

* * *

REFERENCES

1. Mach, E., "Grundlinien der Lehre von den Bewegungsempfindungen," p. 128, Leipzig: Wilhelm Engelmann, 1875

2. Clark, B., and Graybiel, A., "The Effect of Angular Acceleration on Sound Localization: The Audiogyral Illusion," J. Psychol. 28: 235-244, 1949

3. Graybiel, A., Kerr, W. A., and Bartley, S. H., "Stimulus Thresholds of the Semicircular Canals as a Function of Angular Acceleration," Amer. J. Psychol. 61: 21-36, 1948

AGE AS A VARIABLE IN POST-ROTATIONAL PHENOMENA*

Frederick E. Guedry, Jr.
Tulane University
New Orleans, Louisiana

INTRODUCTION

In previous studies of post-rotational experiential phenomena (1,3), it was found that the mean duration of the first post-rotational apparent-motion effect was of the order of 20 seconds on the initial rotation. The subjects used in these studies were between 19 and 24 years of age. In subsequent experiments involving conditions similar to the previous studies, a few older subjects were employed as preliminary observers because of their immediate availability. It was noted that these subjects reported illusions of longer duration than the younger subjects in the previous studies.

The present report is concerned with an investigation of the possibility that the differences noted above may be attributable either to chance or to slight differences in experimental conditions.

Frederick E. Guedry, Jr., received his B.A. from Tulane University in 1943. After spending three years in the Navy, he resumed his study of psychology at Tulane and received his M.S. in 1948. Following this, he became a research assistant with the Tulane University - Office of Naval Research project at the Naval School of Aviation Medicine, Pensacola. At present, he is nearing the completion of the requirements for the Ph.D. degree in psychology at Tulane.

PROCEDURE

The principal item of apparatus was a Link trainer, so modified that it could be rotated in the horizontal plane up to 26 rpm and could be controlled from an adjoining room. A strut projecting from the front of the fuselage provided rigid support for a 3 x 3 x 6 inch black box with perforated edges which was illuminated from within so as to be visible to subjects at a distance of 2 meters. In the cockpit was an iron stanchion supporting a bite-board which served to keep the subject's head fixed over the center of rotation and tilted slightly forward. The trainer occupied the center of a twelve-sided, lightproof room.

Subjects were divided into two groups on the basis of age: Group I consisted of 24 Naval ROTC midshipmen between the ages of 19 and 21 years. The selection of Group II was based on the criterion that all 24 subjects be at least 30 years of age or older. (Previous experimentation has indicated that at least 20 subjects in each group would be desirable in a study of this type because of intersubject variability even with subjects of the same age.) The mean age of Group II was 38 years, $\sigma = 6$; the age range was from 30 to 53 years.

All subjects yielded a report of the duration of the first post-rotational effect in each of two trials separated by a 3-minute interval under the following experimental conditions. Each subject was rotated for 60 seconds with controls set to achieve 20 rpm. This yielded 44.5 seconds of rotation at 20 rpm since 15 seconds elapsed during positive acceleration (0 to 20 rpm) and about 0.5 seconds elapsed during negative acceleration (20 to 0 rpm). The experimental room was in complete darkness except for the light from the perforated box which was not of sufficient intensity to make the walls of the room visible.

*ONR Project NR 143-455, Contract N7onr-434 T.O. 1

The subject indicated cessation of the first post-rotational effect by pressing a key which caused a light to flash in the control room. A standard electric timer enabled the experimenter to measure the duration of the illusions.

RESULTS

The results are indicated in Table 1 where the values in the Group I and II rows represent the mean durations of the first post-rotational effect for Trial 1 and Trial 2.

Although there is considerable overlap of the distributions yielded by Group I and Group II (cf. Range Group I and Group II rows in Table 1), this was to be expected from the individual differences noted in previous studies with subjects who were of the same age. However, the t values of Table 1 indicate that the differences between the mean durations are not attributable to chance.

TABLE 1

Comparison by Groups of the First Post-Rotational Effect for Trials 1 and 2

	Trial 1	Trial 2
Group I	24.7 sec	25.2 sec
Group II	31.1 sec	33.1 sec
Range Group I	15 to 40 sec	12 to 35 sec
Sigma Group I	5.56	6.44
Range Group II	14 to 49 sec	17 to 46 sec
Sigma Group II	4.55	6.56
$M_{II} - M_I$	6.4 sec	7.9 sec
t Values	3.88	4.14
Probability	0.001	0.001

DISCUSSIONS

Explanation of the fact that older subjects tend to yield reports indicating longer durations of post-rotational apparent-motion phenomena than younger subjects under identical experimental conditions is a matter of conjecture. Four possible explanations are suggested:

(a) Older subjects may tend to be more cautious and hence delay their reports until they are confident that apparent motion has ceased even though instructions are identical for both old and young.

(b) Dodge (2), Wendt (4), and Brown and Guedry (1) have inferred from their findings that there are two competing response systems with rotary stimulation, a central process and a vestibular reflex system. It is possible that older subjects may have less central control over the vestibular reflex system. An inference from this explanation is that older subjects may not habituate to rotation as readily as younger subjects. This inference is prefaced by the contention of Dodge and Wendt that habituation occurs when the vestibular system, which is at first dominant, becomes subordinate to a central process.

(c) Not only were Group II subjects older than Group I subjects, but Group II was not screened as carefully for poor eyesight, ocular muscle imbalance, etc., whereas Group I subjects were Naval ROTC midshipmen who had passed a fairly rigid physical examination. If poor oculomotor control or generally poor vision is an explanation of the difference between Groups I and II, then perhaps young subjects with similar visual defects would yield durations comparable to Group II.

(d) A fourth possibility is that the condition of the semicircular canals changes with age.

* * *

REFERENCES

1. Brown, R. H., and Guedry, F. E., Jr., "The Effect of Visual Stimulation on Habituation to Rotation," J. Gen. Psychol. (in press)

2. Dodge, R., "Habituation to Rotation," J. Exp. Psychol. 6: 1-35, 1925

3. Guedry, F. E., "The Effect of Visual Stimulation on the Duration of Post-Rotational Apparent Motion Effects," J. Gen. Psychol. (in press)

4. Wendt, G. R., "An Interpretation of Inhibition of Conditioned Reflexes as Competition between Reaction Systems," Psychol. Rev. 43: 258-281, 1936

THEORETICAL

THE OPERATING PRINCIPLE OF THE VESTIBULAR MECHANISMS*

Robert Mayne
Goodyear Aircraft Corporation
Akron, Ohio

In the analysis of high-speed flight we must sooner or later come to grip with the integrated man-aircraft system. The behavior of this system must be optimized and research should be oriented towards the discovery of the basic information required for this purpose. The characteristics of the airplane itself are well known and there are well-established techniques to predict its behavior provided the reactions of the pilot are known. There are, however, no similar knowledge and technique to predict the reactions of the pilots with a satisfactory accuracy. "The Mechanism of Spatial Orientation" with which this symposium is concerned is an important component in determining the behavior of the sub-system-man in the over-all man-aircraft system.

Robert Mayne, born in France, came to America at an early age. After graduation from Drexel Institute of Technology with a B.S. in Electrical Engineering in 1926, he became engaged in various phases of research and development in automatic control and rubber. In 1942 he joined the Goodyear Aircraft Corporation and eventually became manager of the Aerophysics Department.

I should like to discuss here a further subdivision of the mechanism of spatial orientation, the labyrinth, and suggest a likely principle of its operation. It is a basic tenet of one of the branches of psychology that the whole is not the same as the sum of its parts. This is certainly true of physical science; but it cannot be denied that the whole is some sort of function of its parts, and we have no other course but to dissect a system into components if we are to understand its "integrated" operation. This is a proper procedure provided the "integration" is not simplified to a simple addition. In engineering we find the two words "system" and "components" very useful in distinguishing between the integrated and the dissected aspect of a mechanism.

In the discussion of the vestibular mechanisms I shall emphasize the normal rather than the abnormal behavior. If we are to understand the contribution of these organs to the orientation or disorientation of a pilot in the complex situations of modern high-speed flight, we must understand its operation in the normal situations of everyday life. We must know what functions it is intended to fulfill if we are to visualize what functions it cannot perform. We must define the nature of the information it normally supplies if we are to predict what misinformation it may occasionally dispense.

It seems proper that we should bring our combined techniques to bear on the problem. With the present intensive search and research in all the specialized fields of science, the most secure hiding place for solutions to refractory problems is no doubt in the no man's land which lies between these fields. I judge by the title of this symposium that psychology and physiology have already joined in the hunt. It is now my part to bring up engineering as reenforcement. Let us hope that together, we may be able to flush up our game.

I must warn you, however, that there is an element of danger in inviting me as representant of a discipline of the dead world into your rich domain of the living world. I should think that you would be particularly wary of "Control and Communication Engineering" in view of its recent attempt to claim as its own the whole field of human behavior, of abnormal psychology, and of the processes of reason. But there are indications that we are learning good manners and the place where we belong. The realization that a digital computer can never be a brain, no matter what the number of its elements, is now becoming increasingly clear to many of us. Still control and communication engineering should

---

*By invitation

have a place, together with other disciplines, in the attempt to formulate a theory of spatial orientation. There would have been little progress in the development of a theory of vision without optics and the discipline of camera design. The fact that the function of the vestibular organs is still obscure may be traced in part to a failure to have applied related techniques of the physical world, particularly those techniques associated with the design of physical stabilization systems.

It is my purpose today to present a thoroughly mechanistic interpretation of a limited phase of the operation of the vestibular mechanism in terms of control engineering. I shall also try to be very clear in an attempt to establish a common ground between our respective fields. But it may as well be realized that the concepts which are most easily taken for granted in a field of specialization and which are called "elementary" are those which are most difficult to accept when they are first presented. It is in these difficult elementary concepts that we must deal in our first contacts.

I believe that the vestibular mechanisms function to provide spatial reference by a process of double integration of acceleration. The theory of this process, as it is believed operative in the semicircular canals, was advanced in a recent paper of mine* and I shall amplify somewhat on the original presentation.

The motion of the fluid in the semicircular canals was defined in the above paper by an equation of the form:

$$m \frac{d^2 \epsilon}{dt^2} + c \frac{d\epsilon}{dt} + K\epsilon = mg(t) \qquad (1)$$

where ϵ = displacement of the endolymph with respect to the walls of the canals
c = the damping constant of the system
m = the mass of the system
K = the stiffness constant of the system
$g(t)$ = the input linear acceleration of the walls of the canals.

This equation states in symbolic terms what physical forces are acting on the endolymph. Let us examine the meaning of these symbols. Also, for the moment, let us forget anything we may know about calculus and differential equations. This knowledge is only necessary for the manipulation of the symbols in finding a solution to the equation. We may well consider this manipulation below our human dignity and leave it to a machine, which can do a much better job than we can.

The first requirement in dealing with a dynamic problem, such as symbolized by the equation, is a clear distinction between displacement, rate of change of displacement, rate of change of the rate of change of displacement, etc. Dynamics began when such distinction emerged from the confused concept of motion. It was perhaps one of the most significant events in science. I believe that it makes more sense to speak of scientific progress as a gradual clearing up of confusion than as a continual discovery of new truths.

Let us call X the distance of a particular point along a certain axis to another point which we may use as a reference. If X is changing continuously we can speak of its rate of change as a quantity distinct from X. This approximate rate of change can be obtained at any point by taking a certain change in X and dividing it by the time taken to effect it. Any degree of accuracy can be obtained by making the change in X and the corresponding time t small enough. As you know the rate of change at a point is symbolized by the expression dx/dt.

The symbol, dx/dt, then signifies "velocity at a point X." It expresses also the fact that this velocity was obtained by taking a very small change in X and dividing it by the corresponding small time required to effect it. If you are traveling in your automobile, you may obtain a very rough approximation of your speed at any point by dividing the total distance covered by the total driving time. A more accurate approximation would have been obtained if the time required to travel a short distance at the point in question, say 1/10 of a mile, had been determined and this time divided into the distance. The dimensions of velocity as you well know is distance divided by time.

---

*"The Dynamic Characteristics of the Semicircular Canals," The Journal of Comparative & Physiological Psychology, Vol. 43, No. 4, August 1950

Similarly the expression d^2x/dt^2 symbolizes the rate of change of the rate of change of distance with respect to time. It is an expression of acceleration at any point. Many problems involve higher derivatives of X but in our case we may stop at the second.

If now we take the acceleration d^2x/dt^2 in a given direction at a given time and multiply it by a number of seconds, we shall obtain the change of velocity during that time under the assumption that the acceleration remains constant during the interval. If we add together all these changes of velocity for a certain total time, we obtain the approximate total change of velocity dx/dt. Our approximation becomes better and better as we divide the total time into smaller and smaller intervals. The process of multiplying the values of acceleration at various times by a small time interval and adding all the products is called integration of acceleration. If this integration is performed along a given direction, and if the initial velocity is known, it will give the velocity at any time and position in this direction. If now a second integration is performed, it will give position X at any point and time. It is believed that the vestibular mechanisms operate in collaboration with the neural centers to perform 12 double integrations of acceleration, including 3 angular and 3 linear operations in two directions. It appears that the vestibular organs produce a certain level of signal at zero excitation and that the signal is increased for increased velocity in one direction and reduced for increased velocity in the opposite direction. Right and left organs seem to overlap somewhat for right and left indications, but the function of detecting velocity in a given direction is mainly assigned to one organ. The actual velocity is given by the difference between the right and the left organ signal level. We shall proceed to indicate the mechanism of this operation of double integration.

As mentioned above we must consider the value of the function X and of its various derivatives as separate realities. Each has its own effect independently of the other. The fact that you may be thrown against the front seat in a car is only related to the acceleration and has nothing to do with the speed of the car or whether the car is in Pensacola, Florida, or Akron, Ohio. The force of the air on the windshield is only related to the speed of the car with respect to the air. The landscape outside the window depends upon location and has nothing to do with either speed or acceleration. Similarly, as we study the forces acting on the fluid of the semicircular canals we find that the displacement of the fluid, the velocity, and the acceleration make separate contributions.

Take for instance the term $K\epsilon$ in the equation. This term states that a force proportional to the displacement of the fluid is exerted upon it. This force originates from the spring action of the cupula. We have assumed that this force is springlike and linear where the constant K represents the relation between force and displacement. This is likely to be the case for small displacement of the cupula.

The term $c(d\epsilon/dt)$ defines another force which is porportional to velocity. This force is due to the viscosity of the fluid. It is well known that the proportionality between force and velocity holds for small diameter tubes, and so called laminar flow.

According to Newton's law the sum of these two forces must equal the product of the acceleration of the fluid by its mass. But the acceleration of the fluid is the difference between the acceleration of the wall and that of the fluid with respect to the walls, so that we can write:

$$m\left[\frac{d^2x}{dt^2} - \frac{d^2\epsilon}{dt^2}\right] = c\frac{d\epsilon}{dt} + K\epsilon \qquad (2)$$

which is equivalent to Equation (1).

Now the constants of the system are so selected (if the teleological implication in the use of the term "selected" can be forgiven) that the terms $d^2\epsilon/dt^2$ and $\frac{K}{m}\epsilon$ can be neglected for normal body activity. Then approximately

$$\frac{d^2x}{dt^2} = \frac{c}{m}\frac{d\epsilon}{dt} \qquad (3)$$

and by integration of both sides (if I may be allowed a simple calculus transformation), we have

$$\frac{dx}{dt} = \frac{c}{m}\epsilon + C. \qquad (4)$$

Under normal conditions when a motion starts with the fluid properly centered and with zero velocity C = O. This equation states that the displacement of the cupula is proportional to the velocity of the walls. If now the cristae emit electrical pulses of a frequency proportional to the cupula displacement, a count of these pulses will be a second integration of acceleration and will represent positional information. We can assume that this count is kept in the neural centers by some type of digital counter.

A few manipulations of the equation would allow us to predict several of the well known phenomena of vestibular stimulation. It will account for the absence of signal when a subject is rotated at a constant speed, for the post-rotational effects, and for confusion at a low frequency of oscillation. I may say, however, that it will not account alone for nystagmus and for the audiogyral illusion, which phenomena are believed to include other mechanisms beside the one described here.

The above discussion has been limited to the semicircular canals, which are organized to detect angular velocity. It seems reasonable that a similar set of organs should exist to detect linear velocity. It is suggested that the saccule and associated canals, macula, and otolith are responsible for this function. The action of linear acceleration is exerted on the walls of the saccule with their load of otolith. Since the saccule is approximately spherical, no distortion of the walls can take place without a flow of the endolymph through the small canals connecting it to other sacs. An integration of acceleration into velocity takes place, therefore, as in the case of the semicircular canals. A definite shape of the walls of the saccule must correspond to a certain pattern of velocity and therefore to a pattern of signals.

Let us try to summarize the matter discussed above. An observer who has no contact with the outside world can keep track of his position by a process of double integration of acceleration provided he is informed of the position of his starting point, and of the pattern of velocity at this point. He will require two basic instruments: a clock and a set of accelerometers, including three linear and three angular accelerometers, assuming that these instruments can measure positive and negative quantities. He will also have to perform certain logical operations on the data obtained in this manner.

The vestibular organs are believed to constitute the equivalent of a combination of clock and accelerometers suitable to perform the first integration of acceleration. If this character of their structure is not apparent from the above discussion of the equation, the reader may think of an hourglass. The speed of the sand through the glass depends on the acceleration (1 g when the glass is stationary) and the accumulation of sand to an integration of acceleration with respect to time.

The second integration of acceleration is believed to take place in the neural centers, which are also responsible for the logical operations required to determine positional changes. Some of the limitations of the system were outlined in the above mentioned paper.

* * *

THE RELATION BETWEEN VISUAL AND POSTURAL DETERMINANTS OF THE PHENOMENAL VERTICAL*

James J. Gibson
Cornell University
Ithaca, New York

Fifteen years ago, Koffka pointed out that perceived space could be characterized as constituting a sort of "framework." Implicit in every visual perception were vertical and horizontal, reference-axes somewhat analogous to the coordinate axes of abstract geometrical space. Not only the perception of the position of objects but also the perception of one's own bodily posture depended on this framework. In Koffka's theory the "ego" was a part of the phenomenal field, an entity in perceived space; and consequently the maintaining of bodily equilibrium was for him essentially a perceptual process, of which the postural reflexes were simply an expression.

James J. Gibson, Professor of Psychology at Cornell University since 1949, received his B.S., M.A., and Ph.D. degrees from Princeton University. During the war, he was director of an AAF research unit concerned with perceptual aptitude testing and problems of perceptual learning. Dr. Gibson taught at Smith College from 1928 to 1949.

Koffka reached the conclusion that this phenomenal framework, this sense of the vertical which a man possesses, was determined by visual stimulation. More specifically, it depended on the main contours of the visual field such as are provided by walls, floors, and the horizon. He based this conclusion in part on some rather informal observations by Wertheimer which indicated that a visually tilted room will look upright to an observer if he continues to look at it for a long enough time. In 1938, three years after Koffka's book, I suggested, in collaboration with Hobart Mowrer, that the visual vertical and horizontal are not determined by visual cues but by postural stimuli, and ultimately by the force of gravity acting on the body. The theory was that posture was the primary capacity of an organism and the ability to see the directions of up-down and right-left was secondary. This conclusion was based on observations which contradicted those of Wertheimer and indicated that a visually tilted room will never look upright to an observer. Instead, a sense of the physical vertical seemed to persist and the artificial environment continued to look tilted by reference to it. A fairly clear issue seemed to emerge which was in need of decision or resolution. Of the two kinds of available cues, the lines on the retinas on the one hand and the vestibular-kinaesthetic stimuli for bodily equilibrium on the other, which are decisive in the event of conflict between them? The original observations, both Wertheimer's and my own, were based on a few subjects and no precise measurements were made. The experiment needed to be repeated. Other methods of putting visual and postural cues into conflict, such as modifying the direction of gravity by a centrifugal force also needed careful investigation.

In the 12 years since 1938 a considerable body of facts has been accumulated which bears on this issue. Since orientation to gravity on the one hand and to the visual horizon on the other is one of the classical problems of aviation medicine and aviation psychology, this research has properly been supported by the Office of Naval Research. The evidence comes mainly from a series of experiments begun by Asch and Witkin in 1942 and from another series of experiments carried out jointly by the U.S. Naval School of Aviation Medicine and by Tulane University, under the direction of Graybiel and Mann respectively.

Without attempting to summarize all this evidence, it is fair to conclude that the issue has not been decided. The observers at Brooklyn College employed by Witkin make judgments of the vertical axis of space which are much influenced by the direction of the lines in the visual field and little influenced by

---

*By invitation

the direction of the pull of gravity on the body. Individual differences are prominent. The observers employed at Pensacola and Tulane make judgments of the vertical which are little influenced by the lines in the visual field and much influenced by the axis which the body must adopt in order to maintain equilibrium. Individual differences are not great. The two sets of results appear to be in disagreement. Is there any way in which both can be accepted as correct?

The purpose of this paper is to suggest that the issue formulated above cannot be decided one way or the other and needs to be resolved instead. In making this suggestion, I am admitting having made what seems to me now a mistake. The controversy arises only if one is forced to choose between a phenomenological theory of space-perception, such as Koffka advocated, or a motor theory of space-perception such as was implied by Mowrer and me in 1938. Let us follow these opposed theories to their ultimate conclusions.

The Gestalt psychologist would like to demonstrate that perception is prior to action. Hence he assumes that the maintaining of bodily equilibrium is a matter of perceiving one's body-position. The ego is part of a field and the postural reflexes are to be understood as forces in the field. This says, in effect, that a man must be able to sense the vertical in order to stand up. Hence the upright posture is nothing but a secondary resultant of the spatial framework.

The behavior theorist would prefer to believe that action is prior to perception (if it came to a choice). He assumes that equilibrium is maintained by reflex adjustments and that one's sense of the vertical is merely the conscious accompaniment of this process. A man has to be able to stand up in order to sense the vertical. Hence the spatial framework is nothing but a secondary resultant of the postural vertical.

When the theories are contrasted in this fashion the difference between them begins to sound like a terminological problem or at most a philosophical question which no amount of evidence will settle. Is it really profitable to debate whether an animal must perceive the environment before he can orient to it or whether he must orient to the environment before he can perceive it? Psychologists have differed on just such questions for years but I suspect that the argument is fruitless. Why must we suppose either that perception is prior to posture or posture prior to perception? Why not assume that they develop together, both ontogenetically and phylogenetically?

The evidence indicates clearly that the apparent visual vertical, as judged by an experimental observer, is determined by both visual stimulation and postural (gravitational) stimulation acting jointly. The evidence is equally clear that the achieving of a vertical posture (in a tilting chair, for instance) is determined by both visual stimulation and postural stimulation acting jointly. The apparent visual vertical is the standard by which we perceive the upright or tilted quality of objects, the horizon, and the visual world around us. The postural vertical is the norm which an animal achieves by tonic muscular reactions which keep it in balance. The visual phenomena and the motor ability are closely interrelated. Both are necessary if an animal is to see effectively and act adaptively. In all likelihood they are correlative, and neither has to be taken as the explanation of the other. We neither have to see in order to stand nor do we have to stand in order to see.

When this theoretical issue is disposed of, the question of visual cues versus vestibular and kinaesthetic cues appears in a new light. Spatial behavior and spatial perception depend on both modes of stimulation. The question is no longer which mode is decisive when they are set in conflict but simply how do they interact when in conflict? In normal upright posture in a normal environment the main lines of the retinal image are physically parallel to the direction of gravity acting on the body. When these directions are not physically parallel, the situation is one of conflicting or discrepant cues. This latter situation can be produced for an experimental subject by rotating his retinal images either by optical means or by actually tilting the environment which determines his retinal images. It can also be produced by altering the effective direction of gravity by adding a component of centrifugal force, without rotating the retinal images. In either case the effect is to make the subject try to perceive two incompatible verticals and try to adopt two incompatible postures. In this kind of a situation the subject must respond either to the retinal cue or the gravitational cues, or to a compromise between them, or first to one and then to the other.

It is important to note, at this point, that the situation of discrepant cues is not produced when the subject alone is tilted, either in a tilting chair or by voluntarily reclining or putting his head to one side. In this case, which is common, in the activities of daily life, the lines of the retinal image remain

physically parallel to the direction of the pull of gravity, at least approximately. On the one hand, the environment together with its projected image and on the other the forces acting on the vestibular organs, the skin, the joints, and the muscles are consistent with each other, not discrepant. When, for example, a man lies on his side on the beach and looks off at the horizon of sea and sky his retinal image has been rotated 90° out of the normal, but at the same time the pressure within his inner ear has also been rotated 90° out of the normal in the same direction. Whether he tilts his head 90° or 60° or 30° the stimulation of the retina and that of the statocyst remains consistent and may be assumed to have a sort of angular correspondence.*

This situation may be called one of consistent cues or, preferably, one of reciprocal stimulation. To each degree of variation in retinal stimulation there is a corresponding variation in kinaesthetic stimulation; the two are coupled together. In this situation the achieving of an upright posture is natural, easy, and accurate. A subject in control of a tilting chair under these conditions can bring himself into alignment with gravity with great precision. The tilted subject in an upright environment also perceives the environment as upright and discriminates the visual vertical accurately.

The above result is in striking contrast with that of the upright subject in a tilted environment. The latter may or may not perceive the tilt of the environment, and he can discriminate the visual vertical only with a considerable error and with much variability. In both subjects there has been a rotation of the retinal image out of the normal, but in the latter case there is no reciprocal variation in the accompanying postural stimuli. The two modes are still coupled but the stimulus-variables do not correspond. The rotation of the retinal image is not compensated by a corresponding angular shift in the proprioceptive complex.

The theory which emerges from these considerations is something like this. In the case of reciprocal visual proprioceptive stimulation, the coupled variables combine to form an invariant† resultant which is in correspondence with the objective direction of gravity and which provides the stimulus for a univocal impression of the vertical. This is why the ordinary visual scene continues to look upright when one inclines his head and thereby rotates his retinal image. In the case of discrepant visual-proprioceptive stimulation, or conflicting cues, the coupled variables do not yield an invariant. Their values do not correspond in the usual fashion and the resulting perception is ambiguous or equivocal. The subject is instigated to perceive two different verticals at the same time. The organism is forced to choose between them. Accordingly it is not surprising that the resulting perception is unstable and that it differs from one subject to another, as Witkin has discovered. Determinants of perception other than stimulation are free to function—attitudes, expectations, and habits characteristic of the person observing in the situation.

Here, in truth, is the case where the perception can be said to be determined by cues instead of by stimulus-variables. The observer must search for clues to, or indicators of, the direction of gravity. His perception is objectively correct only to the extent that reliable clues are discovered, and consistently correct only to the extent that they are verified and learned.

The explanation of space-perception in terms of cues is crude and unsatisfactory as compared with an explanation in terms of stimulus-variables, but is sometimes useful. Let us apply the language of cues to the case of the subject seated upright in a tilted room. His retinal image of the environment taken by itself tells him that his head and body are inclined away from the vertical (this being the ordinary and almost invariable cause of a tilted retinal image). But his inner ear, his muscles, and the seat of his pants tell him that his body is not inclined from the vertical. Which sense is he to believe? If he believes his eyes he should attempt to align his head with the room and when asked to rotate the adjustable stick into a vertical position he sets it nearly or completely parallel to the side walls. The room appears nearly or wholly upright. On the other hand, if he believes his body-sense but not his eyes he

---

*This formulation, it is true, neglects the slight counter-rolling of the eyes when the head is tilted. But this adjustment may be conceived as simply a part of the compensatory perceptual-motor mechanism being described, which complicates but does not invalidate the theory.

†The hypothesis of an "invariant of stimulation" in a number of perceptual situations was the insight which enabled Koffka to comprehend the problems of perceptual constancy more clearly than any other investigator. This hypothesis may be adopted without accepting his theory of field-forces in perception. The above application of the concept of an invariant is quite different from that of Koffka (Principles, p. 215-218), but conception itself is his.

should sit askew of the room and he sets the stick in line with the main axis of his body. The room appears to be strongly tilted relative to a larger space outside. If he cannot decide between his senses, he may begin to make inferences—unconscious inferences, according to Helmholtz. If he has been told to set the stick to the true vertical, for instance, he may reflect upon the fact of gravity and balance and decide to put trust in the body cues. If he scans the visual evidence, however, the retinal lines argue forcibly that his head must be tilted when he holds it physically upright, and upright when he holds it physically tilted.

The explanation of why Witkin's observers tended to see the vertical in alignment with the room whereas the Pensacola-Tulane observers tended, in similar situations, to see the vertical in alignment with gravity may not be so difficult, after all. If slight and subtle differences in the attitude of the subjects can affect the judgments, this may be sufficient to supply the explanation. The very meaning of the term "vertical" can be ambiguous in the situation described, and one group of subjects may have understood by it the apparent vertical while the other group understood the objective or physically correct vertical.

According to the theory outlined, ambiguous, equivocal, or unstable perceptions of space are the result of the absence in stimulation of a visual-proprioceptive invariant. This is the situation which we have been satisfied in the past to call one of "conflicting cues." Along with the unstable perception goes an unstable posture, i.e., some degree of disequilibrium. It is important to study this situation, but it is even more important to understand the basic stimulus-situation from which it differs. The reciprocity of vision and proprioception in everyday spatial behavior may prove to be illuminating not only for the problem of upright posture in relation to the visual vertical, but also for the problem of eye movements and other compensatory reactions in relation to orientation in the plane of front-back-right-left. The covariation of vision and proprioception is probably at the heart of the problem of locomotor behavior, pursuit tasks, and many other motor skills.

It is important to realize that the individual differences which Witkin finds to be so striking in the situation of conflicting cues are, in all probability, a function of that situation. He has not demonstrated that individuals differ in the basic ways in which they perceive space, but only that they differ in their choice of alternatives when several possibilities for perception are open—when the process of spatial perception is ambiguous. When the stimulus conditions are indeterminate, the outcome will be influenced by attitudes, motives, and even social background, sex, and temperament.

On the other hand, the situation of conflicting cues is not without practical importance, nor is it wholly unrepresentative of spatial behavior. Equilibrium and orientation in an airplane and other complex forms of spatial behavior mediated by instruments probably involve some degree of conflict or discrepancy among cues. The practical problem here is that of learing to use the reliable cues and to neglect the unreliable and irrelevant ones.

* * *

SOME STUDIES OF VISUAL PERCEPTION OF MOTION*†

William H. Ittelson
Princeton University
Princeton, New Jersey

INTRODUCTION

Many familiar demonstrations of phenomena involved in static visual perception are available to the classroom instructor and the laboratory investigator. In contrast, few demonstrations concerning the perception of movement are in common use: unfortunately the study of motion perception forces one to replace paper and pencil with elaborate and often expensive mechanisms. Understanding has not been entirely thwarted by complexity and cost, however, and a growing body of literature is available dealing with diverse aspects of this question. This paper will describe three demonstrations which, taken together, encompass a fairly wide area of the visual perception of movement.

William H. Ittelson, after obtaining his B.A. degree in 1941, received a B.S. in Electrical Engineering in 1942, both from Columbia University. He then worked a year for the Naval Research Laboratory, Washington, D.C. before entering the Naval Reserve as an Airborne Electronics Officer. After leaving the service in 1946, he taught and studied at Princeton University where he received his M.S. in Electrical Engineering. During this period his major interest shifted to psychology; in 1948 he became affiliated with the Department of Psychology at Princeton and received the Ph.D. degree in 1950.

It seems useful at the outset to distinguish between two different principal directions of perceived movement. One, directly toward or away from the point of observation, can be labeled radial movement, while the other, at a constant radial distance, can be termed tangential movement. These principal directions of motion are clearly analogous to the familiar static depth and direction, and, just as in the static case, one would expect different types of cues to be utilized by the organism in the two different cases.

RADIAL MOTION

This demonstration is concerned with the role of continuous change of size as an indication of continuous movement in a radial direction. That such an effect does take place was apparently first appreciated by Wheatstone (13) and has since been studied in a variety of contexts (1,3,7,8,11). The apparatus discussed below contains within it means for demonstrating virtually all that is known regarding this particular phenomenon.

A light box (A in Figure 1), on the front of which is a square diaphragm opening (B), is driven back and forth on a track (C,C) through a distance of 6 feet by an electric motor. The opening is observed, in an otherwise dark room, from a distance of 6 feet from the shield (F) at the near end of the track. The square diaphragm opening is formed by two metal plates (D,D) moving in slots on the front of the light box. Each of these metal plates engages one of a second pair of tracks (E,E) whose inclination and separation can be varied. As the box moves back and forth, variations in the size of the diaphragm opening are controlled by the inclination of this second pair of tracks. If they are set parallel, the size of the

---

*By invitation

†The demonstrations described in this paper were designed by Adelbert Ames, Jr., and conducted under his direction at the Institute for Associated Research, Hanover, N.H. Special acknowledgement is due the Rockefeller Foundation for the financial aid which made this work possible.

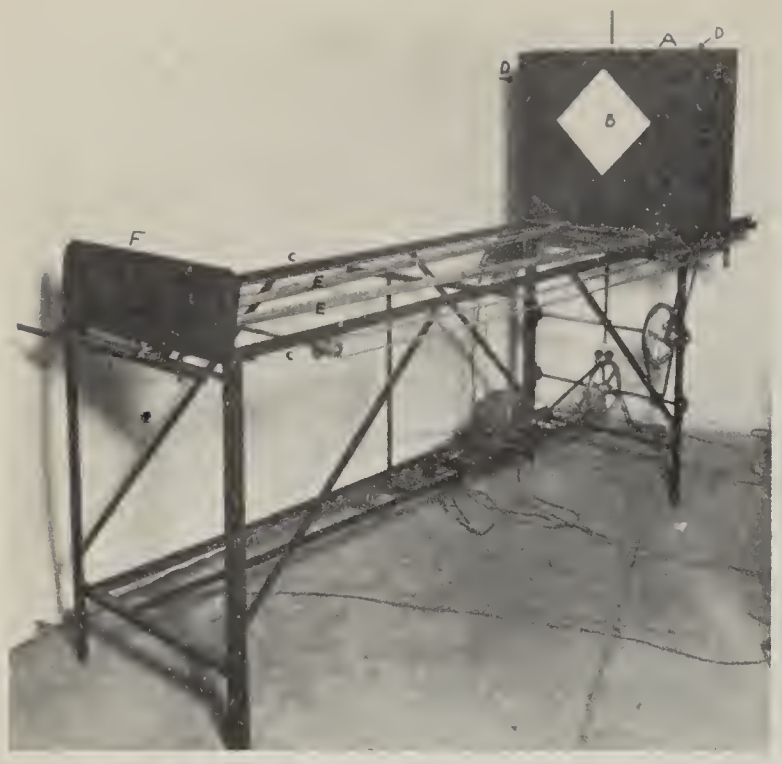

Figure 1 - The radial-motion apparatus. The light box A is driven back and forth on the tracks C and C. As it moves, the size of the diaphragm opening B changes in a manner determined by the setting of the tracks E and E.

opening remains constant. If the tracks are set so that they converge towards the observer, the size of the diaphragm decreases as it moves toward the observer; if they are set so they diverge, the size of the diaphragm increases as it approaches the observer.

When an observer views this apparatus under various conditions of monocular and binocular observation and with various separations and inclinations of the tracks, certain consistent and predictable perceptions are experienced.

1. When the tracks are set parallel, an observer looking with both eyes sees a square of constant size moving back and forth at a constant speed, approaching to a distance from him of approximately 6 feet and receding to a distance of approximately 12 feet (Condition I, Figure 2). His perception in this case corresponds to the actual objective situation.

2. If an observer looks with one eye, he sees substantially the same thing (Condition I, Figure 2).

3. If, under these conditions, the tracks are then converged so that the opening subtends a constant visual angle as it moves back and forth, he sees the square standing motionless at the apparent distance at which it was localized at the moment that the tracks were converged (Condition II, Figure 2).

4. If the tracks are converged still more to just the right amount he will again see a square of constant size moving back and forth at a constant speed through a distance from him of 6 to 12 feet but the apparent direction of movement will now be opposite to that of the actual movement (Condition III, Figure 2).

5. If both eyes are used under the conditions described in 4 above, the effect continues to be experienced by most observers to a greater or less extent, persisting even when stationary objects are placed in the field of view to provide more adequate binocular localization. Great individual variations are encountered here.

A further most interesting phenomenon can be illustrated with this apparatus. The tracks are first set parallel with a medium separation (Condition I, Figure 2). As noted above, an observer looking with one eye sees a square of medium size moving at a constant speed from a point six feet away to a point twelve feet away and back again. The tracks are then moved to their maximum separation, still parallel, thereby simply increasing the actual size of the square (similar to Condition I, Figure 2, but with tracks farther apart.) At the same time the observer is allowed to use both eyes. Under these conditions his perception of the distance, direction, and speed of movement remains unchanged; he simply sees a larger square. After he has looked for a few moments, one of his eyes is blocked off, but again he experiences no significant change in his perceptions. Without giving him any indication of exactly what is being done, the tracks are then quickly shifted back to their original setting (Condition I, Figure 2) giving exactly the same external situation and retinal stimulus pattern which had initially been perceived as a square of fixed size moving at a constant speed from 6 to 12 feet. But now the observer perceives it as a larger square, moving through a greater distance, farther away from him, and at an increased and variable rate of speed.*

*As actually carried out the procedure is somewhat more complicated than indicated here, but has been shortened in the interest of clarity of exposition. Several successive shifts, rather than the one abrupt shift indicated, are necessary in order to maintain perceptual continuity. The net result, however, is precisely as stated.

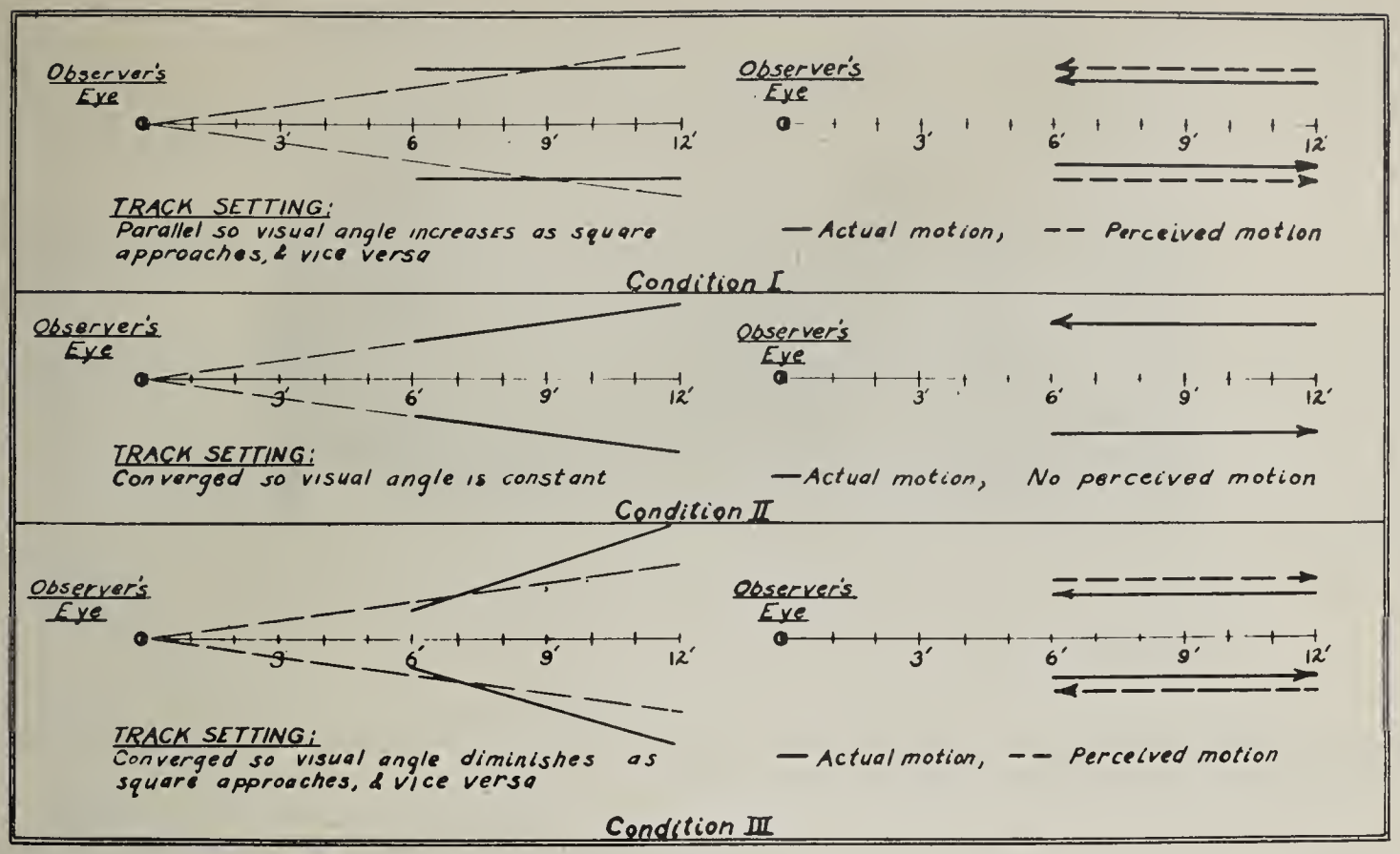

Figure 2 - Perceived motion of the lighted diaphragm (B in Figure 1) under three conditions of observation. The actual motion is the same under all three conditions, but the perceived motion varies with the track setting.

Many variations of this basic effect are possible, involving, for example, a shift toward rather than away from the observer. All of these variations, however, seem to involve the same process. When the observer first looked at the smaller square, he perceived a square of constant size moving back and forth at constant speed from 6 to 12 feet, which in fact corresponded to the actual external situation. In terms of retinal stimulation, this means that a square retinal pattern (disregarding distortion) continuously changing in size was related to the perception of a square of constant size continuously moving in space. When the shift was made to the larger square, the same effect was obtained, reinforced initially by the use of binocular indications. The interesting point, of course, occurs when, in monocular observation, the actual size of the square is reduced to the original, smaller size. It should be noted, that the procedure is such that the observer is unaware of this change and assumes that he is still looking at the larger square. As a result of this assumption* the identical pattern of retinal stimulation, which just previously had been related to the perception of a small square moving at constant speed through a certain distance, is now related to the perception of a larger square, farther off, moving through a greater distance, and at a variable speed. To state this more generally, there are an unlimited number of objective, external events which will produce the same sequence of retinal patterns. Which one of these external events will in fact be perceived depends on the particular assumptions (in this case primarily that of size) which the individual brings to the occasion.

CIRCULAR MOTION

The second apparatus (Figure 3) involves the perception of circular motion. As shown in the diagram (Figure 4), this apparatus contains a mount (A) which is electrically driven so that it oscillates through an arc (BCD) of about 40 degrees at a distance of 8'9" from the observers eye (E). The rate of angular movement about this point (E) is mechanically controlled to be the same as that which would result from an object describing a hypothetical circle (BFDG) with a 3-foot radius at a constant angular velocity about a center (C) 8'9" from E. This means that the angular velocity about the observation point (E) is variable, being zero at the two end-points (B, D) and reaching a maximum halfway between

*The role of assumptions in perception has been discussed at length elsewhere by the authors and others (1,2,4,5,6,8,9,10,12)

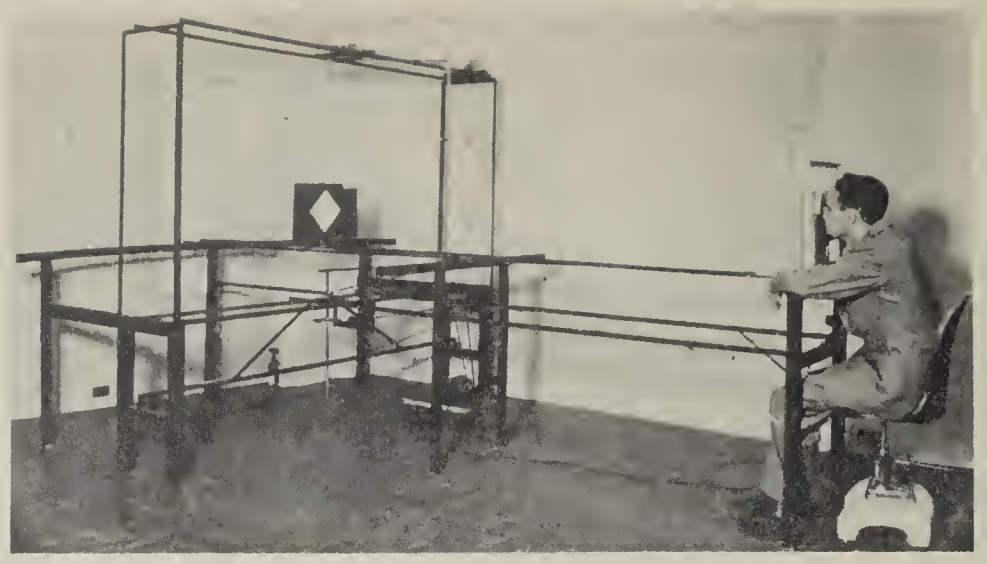

Figure 3 - Circular-motion apparatus showing the light box with variable-size square diaphragm opening in place on the oscillating mount

them. This maximum, furthermore, is greater for movement in one direction (in our case, left to right or BCD) than in the other direction (right to left or DCB).

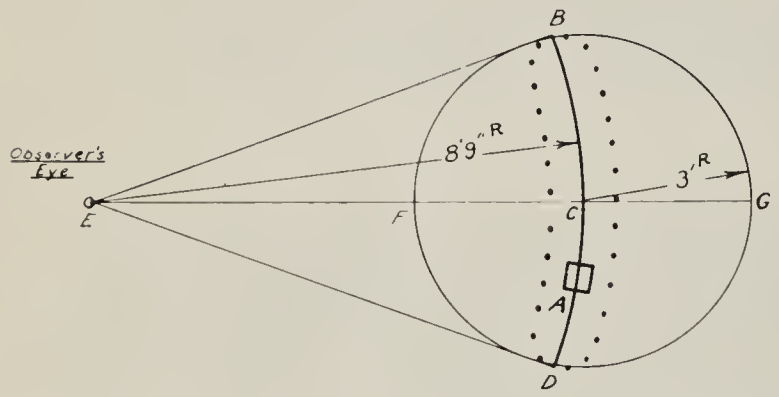

Figure 4 - Schematic representation of the circular-motion apparatus

When a small star point of light is placed on the oscillating mount (A), an observer using one eye in an otherwise dark room sees it as moving in a shallow ovate arc approximately as indicated by the dotted lines in Figure 4. Its apparent speed of movement is variable, being considerably greater in one direction (left to right) than in the other direction. We stress here that the star point does not appear to swing from side to side at a constant distance from the observer as it is actually doing, but rather, it is seen as being appreciably nearer during the period of higher angular velocity and appreciably father away during the period of low angular velocity, resulting in a roughly elliptical path of perceived movement.*

We now replace the star point with a light box having a variable-size square diaphragm opening similar to that used in the radial motion demonstration described above. If the size of this opening is kept constant as the square swings from side to side, the observer, using one eye, sees a constant size square swinging from side to side at variable speeds at a constant distance from him, i.e., true tangential movement at variable speed, which in this case corresponds to the actual movement. It is possible, however, by means of a mechanical linkage, to vary the size of the diaphragm opening in such a way that the angle it subtends to the observer's eye exactly corresponds at all times to the angle that would be subtended by a square surface normal to his line of sight moving in a counterclockwise direction about the hypothetical circle pictured in Figure 4. When the observer now looks at this square diaphragm, which is changing its size at a variable rate and swinging in a shallow arc at variable speed, he sees a square of constant size moving in a circle at a constant rate of speed.

It is evident from the above described effects that objective tangential movement can be related to a number of perceived movements, depending on the other indications available. In the case of the star point, relative angular velocities at different times serve as an indication of relative apparent distances at these times. This effect is clearly related to the familiar depth cue of parallax, with the important modification that the relative angular velocities occur at different times rather than simultaneously. It would seem evident that a perceptual integration along a temporal dimension is involved here.

---

*It is worth noting also that a star point which remains at the same height as the observer's eye and is actually moving in the circle BFDG at a constant speed is perceived in exactly the same way; that is, as moving in the roughly elliptical path indicated by the dotted lines in Figure 4.

However, if angular velocity serves as an indication of distance, even more striking is the effect of apparent distance in determining apparent velocity. Apparent circular movement at constant speed results from the addition of appropriate indications of relative distance. Or, to state this more precisely, circular movement at constant speed is the correlate in experience of appropriate indications of tangential movement at variable speed plus radial movement at variable speed.

TANGENTIAL MOTION: A CASE OF CONFLICT

A given movement across the retina, for example, movement in a constant direction at a constant speed, can be produced by an infinity of external, objective movements; and of course, this relationship becomes even more complicated when eye and head movements and bodily orientation are taken into account. The related perception, however, can obviously be of only one of this infinity of objective conditions. Ordinarily other aspects are available, such as size, brightness, etc., to determine the particular perception, but these other indications are themselves not unequivocal and may even be in conflict. The demonstration described below shows how real, objective tangential movement* may be perceived as a variety of apparent movements when some of the other indications are systematically altered.

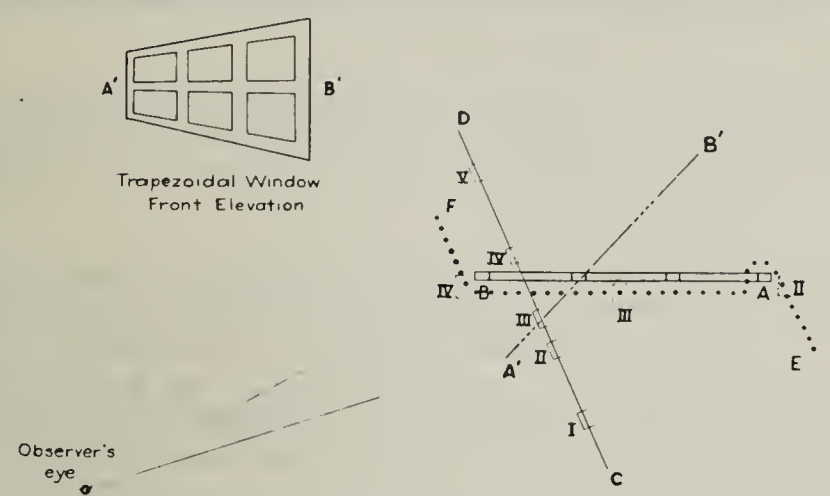

Figure 5 - Diagram showing the real and apparent positions of the trapezoid and the real and apparent paths of the moving card in the tangential motion demonstration. Direction of movement is from positions I to V along the line CD.

A thin metal trapezoidal shape with openings corresponding to window panes (Figure 5) is placed, relative to the observer's eye, in the position A′ B′ (Figure 5). When viewed monocularly under these conditions, the physically near edge (A′) becomes the apparently far edge (A), and the physically far edge (B′) becomes the apparently near one (B). The resulting perception is of an approximately rectangular "window" in the position AB. The photographs in Figure 6 will give an idea of the way in which the trapezoid is perceived.

A small electric motor drives a fine thread in such a way that light objects suspended from it, e.g., a small card cut out of paper, can be driven across the field of view at a constant speed along the straight path CD (Figure 5), passing through one of the near openings of the trapezoid, which to the observer is one of the apparently far openings.

---

*The movement employed in the demonstrations is not, strictly speaking, tangential. It is straight-line movement at right angles to a fixed line of sight, with consequent variation in radial distance. However, since the variation in radial distance is very small in the demonstration, it seems fair to speak of the motion as tangential.

Figure 6 - Photographs showing eight successive positions (A through H) of the card in the tangential motion demonstration. The frame appears to be tipped back with the right side farthest from the camera; actually the reverse is true. The white roman numerals indicate the five positions corresponding to those shown in Figure 5.

However, it is not perceived as moving in such a straight path; rather, it is seen as following the approximately S-shaped course indicated by the dotted line EF (Figure 5). The nature of this illusory movement is dependent on the fact that the observer sees the trapezoid as a rectilinear shape in a position different from its true position. As the card moves across the field of view, it is initially to the right of the "window" and appears against a homogenous background (position I in Figures 5 and 6). Under these conditions it is seen as constant in size moving from right to left at a constant speed in a direction parallel to the observer's frontal plane. When it moves to a position such that part of it is behind the near edge of the trapezoid, it appears to be passing behind the far edge of the apparent rectangle (position II). As the card moves completely through the near opening of the trapezoid, it comes between the observer and successively farther parts of the trapezoid; to him, however, it appears to be passing in front of successively nearer parts of the apparent rectangle (positions III and IV). The card, therefore, appears to be moving toward the observer parallel to the apparent plane of the rectangle and at the same time decreasing in apparent size. It finally appears to pass completely in front of the rectangle and continue to travel in a straight line at a constant speed and size (position V).

In summary of this particular effect, movement of a constant-size object, travelling at a constant speed in a constant direction at a virtually constant distance from the observer, is perceived as an object of varying size travelling in varying directions and at varying speeds and distances. This perceived movement through an approximately S-shaped path is, as indicated earlier, only one of an infinite set of movements which might be perceptually related to the given objective movement. Broadly speaking, this particular effect is achieved by placing the constant size, speed, and direction of the moving object in conflict with the overlay indications from the falsely localized trapezoid. Overlay proves more effective for all observers, and the above described movement is perceived.

Not all, it should be added, see the apparent size change. Many continue to see the moving card as constant in size even when specifically questioned, and in spite of the fact that they perceive the movement in depth quite dramatically. This is merely evidence that, in any perceptual situation involving conflicts, differential individual behavior is to be expected, with greater differences occurring the more nearly the two, or more, possible ways of perceiving are equated in terms of probability of occurrence. This can be most startlingly illustrated with the apparatus described here by placing not only the object, but also the trapezoid in motion. The resulting effects are too complex to be reported briefly and can be found in detail elsewhere (2,10).

SUMMARY

Three demonstrations illustrating various phenomena involved in the visual perception of movement have been described in some detail. The first dealt with the role of continuous size change as an indication of continuous movement in the radial direction. The next demonstration considered indications of radial movement in conjunction with indications of tangential movement, specifically as integrated in a perception of circular motion. The third demonstration treated some aspects of the effect of perceptual conflicts in a situation involving objective tangential motion. Implications for perceptual theory have been briefly discussed.

* * *

REFERENCES

1. Ames, Adelbert A., Jr., "Some Demonstrations Concerned with the Origin and Nature of Our Sensations (What We Experience). A Laboratory Manual " (preliminary draft) (mimeographed), Hanover, N.H.: Hanover Institute, 1946

2. Ames, Adelbert A., Jr.,."Visual Perception and the Rotating Trapezoidal Window," Psychol. Monogr. (in press)

3. Calavrezo, C., "Uber den Einfluss von Grossenanderungen auf die Scheinbare Tiefe," Psychol. Forsch. 19: 311-365, 1934

4. Cantril, Hadley, "The 'Why' of Man's Experience," New York: Macmillan, 1950

5. Cantril, Hadley, Ames, A., Jr., Hastorf, A. H., and Ittelson, W. H., "Psychology and Scientific Research," Science 110: 461-464, 491-497, 517-522, 1949

6. Hastorf, A. H., "The Influence of Suggestion on the Relationship between Stimulus Size and Perceived Distance," J. Psychol. 29: 195-217, 1950

7. Hillebrand, F., "Das Verhaltnis von Accommodation und Convergenz zur Tiefenlokalisation," Z. Psychol. 7: 97-151, 1894

8. Ittelson, W. H., "Size as a Cue to Distance," Amer. J. Psychol. 64, 1951

9. Ittelson, W. H., and Ames, A., Jr., "Accommodation, Convergence, and Their Relation to Apparent Distance," J. Psychol. 30: 43-62, 1950

10. Kilpatrick, F. P., "Some Aspects of the Role of Assumptions in Perception," unpublished Ph.D. thesis, Princeton Univ., 1950

11. Metzger, W., "Tiefenerscheinungen in Optischen Bewegungsfeldern," Psychol. Forsch. 20: 195-260, 1934

12. Smith, W. M., "Past Experience and Perception: A Study of the Influence of Past Experience on Apparent Size and Distance," unpublished Ph.D. thesis, Princeton Univ., 1950

13. Wheatstone, C., "Contributions to the Physiology of Vision, Part the Second," Philos. Mag., Ser. 4, 3: 504-523, 1852

SUMMARY

Capt. Ashton Graybiel, MC, USN and
Cdr. Alan D. Grinsted, MSC, USN
U. S. Naval School of Aviation Medicine
Pensacola, Florida

A review of the several reports and the discussions which followed reveals that many investigators representing many different branches of science are interested to a greater or lesser degree in problems of space perception. It also appears that there has been accumulated a considerable body of knowledge as a result of the work of these many investigators. A consequent need then is to make this knowledge useful in the military situation through its integration and application.

Such conferences as this play an important part in bringing about the necessary integration. In most instances the interest of each investigator is limited to that aspect of the problem which is closely related to his own work rather than to space perception as such, and this results in certain differences in viewpoint. It was revealed in the discussions, for example, that while there was fairly general agreement concerning what was meant by spatial orientation, there was considerable disagreement concerning the intimate mechanisms by which it is accomplished. Another difference in point of view was brought out when an attempt was made to explain the perception of geometrical space. The question arose as to whether we perceive geometrical space as such or whether we perceive it only by virtue of what fills it. It is not always clear whether such difficulty is merely a matter of difference in point of view, or whether differences may result from confusion of terminology employed by those working in different fields. One conclusion is certain—namely, that conferences of this sort are essential to integrate the viewpoints and findings in the various fields in order to accomplish maximum application of our knowledge to the military effort.

The conference also revealed certain research emphases that are not always coordinated with the need to fill gaps in our information. For example, the attempt to explain why we were able to orient ourselves in space was given greater emphasis in discussion than was the problem of why at times we become disoriented. Furthermore, it was clearly evident that we know more about the physical stimuli concerned than we do about the sensory receptors and the nervous excitation to which they give rise. It was also apparent that we know more about the action-current potentials of nerves involved than we do about whatever takes place at the level of perception. There appears to be, then, a place for frequent discussions aimed toward the clarification of research needs and the structuring of goals in the field.

It seems that certain principles might be kept in mind by those working in the field which would do much to enhance the ultimate value of our research efforts. The first would be that the human being functions in relation to a perceptual rather than a physical world. It is valuable to understand the physical stimuli that affect him. It is also extremly helpful in the study of phenomenal space to know all we can about the several sense modalities involved and their individual contributions as they vary under changing circumstances; a complete understanding must await the elucidation of many psychophysiological mechanisms and their interrelationships. However, this understanding will not alter the perception per se, and hence imposes no limitations on investigations which have this as their starting point. Thus,

Alan D. Grinsted, a commander in the Navy Medical Service Corps, has been Head of the Psychology Section of the Naval School of Aviation Medicine, Pensacola since 1949. Commander Grinsted received his B.A. from Bucknell University and his M.A. from the University of Florida. He then taught at the University of Florida, the State University of Iowa, and the Louisiana State University where he obtained his Ph.D. in 1939. He remained at Louisiana State University and became Acting Chairman of the Department of Psychology. In 1941 he became an aviation psychologist in the Navy Department. Immediately after World War II, he was Associate Professor at Rhode Island State College and then at North Carolina State College.

for example, Witkin was able to carry out studies relating individual differences in perception to personality structure without full knowledge of the underlying mechanisms concerned.

Secondly, vital though our basic research may be, it is necessary in an applied situation such as is found in the military forces to keep in mind the goals both of immediate and of ultimate application. Throughout the conference there was the over-all impression that there is much more known than is effectively applied at this time. Some lag between the acquisition of new knowledge and its practical application is inevitable, but a continuous effort should be carried on to ensure that the flight surgeon, the aviator, and the aviation engineer be informed of progress in this area. The need for immediate usefulness however, is not the whole problem. The goal of ultimate application often points the way for the investigator. For example, practical considerations make it apparent that, regardless of whether we perceive geometrical space independently of phenomenal space, the latter may rightly be regarded as our first concern. Similarly, when we recognize that spatial disorientation is of great practical importance in military aviation, the question of why we are able to orient ourselves in space becomes secondary to the problem of why at times we become disoriented. The goal of ultimate application helps give direction to our research efforts, basic though they may be.

Thirdly, it would appear that the need for integration and ultimate application of our knowledge depends heavily upon the clarification of the terminology employed by those working on these problems related to orientation in space. It became increasingly apparent during the conference that, as persons reporting from different disciplines entered the discussion, the same terms did not carry the same meaning for everyone and that this was a major source of misunderstanding. A great service would be performed, therefore, if a committee acceptable to the leaders and the several disciplines concerned were to standardize the nomenclature in this field.

Finally, in view of the limited interest of each investigator in terms of that aspect of the problem most closely related to his work and the consequent detours in thought by which we are all thus endangered, it becomes important to exchange information in further conferences such as this with the consequent correlation of the contributions of the many different investigators.

An over-all consideration of this conference leads to the thought that great as have been the contributions to date they are relatively small compared with what there is yet to learn. It does not require a prophet to point out that many years of hard work on the part of a large number of investigators in physics, the biological sciences, and psychology will be necessary before our understanding will be complete. Indeed it is altogether likely that scientific knowledge as a whole must advance over a broad front before all of the mechanisms involved in spatial orientation will be understood.

* * *

3 0112 077592514